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PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

t No. A-3418 GTRI/~~GIT~~ DATE 11/23/82

: Director: B. R. Livesay ~~School~~/Lab EML/PSD

or: TDK Electronics Co., Ltd.

Agreement: Standard GTRI Research Project Agreement dated 11/1/82

Period: From 12/1/82 To ~~11/30/83~~ 12-31-83 (Performance) ______ (Reports)

or Amount: Total Estimated: $ 111,505 Funded: $ 111,505

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Studies of Magnetic Particle Dispersion Mechanisms and The Physical Behavior of Recording Tape Composites

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2) Sponsor Admin/Contractual Matters:

e Priority Rating: none

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(or) Company/Industrial Proprietary: none

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Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date April 10, 1984

ct No. A-3418 — ~~School~~/Lab EML/PSD

des Subproject No.(s) E-19-620 and E-27-620

ct Director(s) Dr. B. R. Livesay — GTRI / ~~GIT~~

sor TDK Electronics Co., Ltd.

"Studies of Magnetic Particle Dispersion Mechanisms and the Physical Behavior of Recording Tape Composites"

ive Completion Date: 12/31/83 (Performance) 12/31/83 (Reports)

/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
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- [ ] Classified Material Certificate
- [ ] Other ____________

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A-3418

PHYSICAL PROPERTY INVESTIGATIONS

OF

VIDEO RECORDING TAPE COMPOSITES

Prepared For

TDK Electronics, Co. LTD

Tokyo 103, Japan

FINAL REPORT

Project No. A-3418

STUDIES OF MAGNETIC PARTICLE DISPERSION MECHANISMS AND THE PHYSICAL BEHAVIOR OF RECORDING TAPE COMPOSITES

BY

B.R. LIVESAY AND J. W. LARSEN

December 1983

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA USA 30332

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PHYSICAL PROPERTY INVESTIGATIONS OF

VIDEO RECORDING TAPE COMPOSITES

By B. R. Livesay and J. W. Larsen

Georgia Institute of Technology

I. Introduction

A research program was initiated in December, 1982 at the Georgia Institute of Technology to investigate the magnetic particle dispersion mechanisms and the physical behavior of video recording tape materials for TDK Electronics Co, Ltd. of Tokyo, Japan. The work of this research program has been documented in three previous Quarterly Letter reports. The work of the first two quarters was presented in single reports covering all the activities being conducted for TDK under this program. TDK later requested that the subsequent reports be two separate documents, one concerned with the investigations of dispersion mechanisms and the other with the physical property investigations.

The physical property investigations involved two primary tasks;

1. The micromechanical mechanisms affecting the performance and durability of video recording tape structures and

2. Investigations of magnetic characteristics of recording tape materials.

This report describes the physical property investigations for the program.

The micromechanics investigations employed several of the instrumentation systems within the Micromechanics Laboratory at Georgia Tech to study mechanical characteristics of recording tape materials supplied by TDK. A unique microtensile apparatus was used to measure tensile properties of tape specimens stressed under various conditions. A low load friction apparatus provided detailed data concerning the friction characteristics of the tape surface structures. Accelerated wear investigations were carried out using a special apparatus in this laboratory. Microstructural studies were carried out using the scanning electron microscopes at Georgia Tech.

The micromechanical investigations provided new data for the mechanical performance of recording tape structures which had not previously been investigated to our knowledge. Several important degradation mechanisms were identified. The mechanisms were modeled and confirmed with microstructural evidence.

Both the micromechanics studies and the magnetic property investigations carried out at Georgia Tech during the year actually represent an initial stage in the development and application of new approaches which should be pursued in a much more comprehensive program of research. The results from this effort clearly illustrated potentially very important directions for more extensive investigations.

The primary experimental thrust of the magnetic investigations was with the sensitive torque magnetometer techniques since TDK had already explored most of the VSM analysis methods. Liquid magnetic particle dispersion samples measured in both the VSM and torque magnetometer provided interesting data concerning particle orientation. This was discussed in detail in the first quarterly report. Two types of data taken from the planar torque curves, the normalized torque and the skew appear to give the same type of information as the orientation ratio obtained using VSM measurements. The normalized torque is, however, extremely sensitive in the low alignment realm where orientation ratios lie between 1.0 and 1.3. In fact torque methods easily discriminate between 1.000 and 1.001

orientation ratios. The shape of the planar torque curves contains much information on the actual alignment of the magnetic tape samples. A detailed analysis of this shape can give the distribution of particle easy axis orientations. This is a "true" measure of alignment. The theory behind this calculation was discussed in the previous quarterly reports and actual distributions are shown later in Section III.

During the year a new magnetic field pulse unit was developed. This unit is capable of producing complex, fast, high field strength magnetic waveforms which correspond to practically any alignment field which may be employed on magnetic tape production lines. The magnetic analysis techniques devised during the year proved powerful in evaluating the effects of these fields on particle alignment in the tapes. The pulse apparatus features the ability to mimic standard waveforms, to display new trial waveforms and to effectively "freeze" the alignment at any point in the waveform under consideration. These properties when combined with the distribution analysis make this system perhaps the most flexible and most powerful apparatus available for the analysis of magnetic tapes alignments and of the fields that produce them.

The following technical personnel contributed to the work of this program.

1. Mr. Osamu Shinoura, visiting scientist from TDK, spent the full year in our laboratories at Georgia Tech and participated in all phases of these investigations.
2. Dr. Billy R. Livesay, Principal Research Scientist, was the Project Director of the investigations and participated technically in the micromechanics and magnetics phases.
3. Mr. James W. Larsen, Research Scientist, participated in the magnetics and micromechanics phases of the investigations.
4. Dr. Jan W. Gooch, Senior Research Scientist, participated in the particle dispersion investigations.
5. Mr. Leslie E. Henton, Research Scientist, participated in the particle dispersion investigations.
6. Dr. John L. Lundberg, Callaway Professor of Textile Engineering, participated as a consulting expert in polymer science.
7. Dr. Gary W. Poehlein, Professor and Director of the School of Chemical Engineering, participated as a consulting expert in polymer science.

II. Micromechanics of Recording Tape Composites

Several aspects of the mechanical properties of video recording tape materials have been studied at the Georgia Institute of Technology during the last year in a joint research program with the TDK Company. A recording tape must have certain magnetic characteristics in order to provide the storage density and resolution capabilities necessary for the quality reproduction of video signals. It is also essential that the magnetic characteristics of the recording tape material remain stable during the mechanical cycling which occurs in tape recording and play-back operations. A video recording tape thus must be durable when subjected to expected operational and environmental stresses.

The durability of magnetic recording tapes is strongly influenced by micromechanical mechanisms occurring within the composite structure of the tape material. In order to aid subsequent discussions of this research program, it will be useful to briefly review the general physical configuration of the type of recording tapes studied here and to consider some of the stress modes experienced by a tape during normal operation.

Acicular magnetic particles are finely dispersed in polymeric binders and applied as a thin coating on a continuous

Mylar(R) base strip which serves as the substrate for the recording tape. The magnetic coatings studied in this work were about 5 micrometers thick and the Mylar(R) base about 15 micrometers thick. The magnetic particles are about 1 micrometer long and 0.1 micrometer in diameter. The particles are aligned during application of the coating to achieve desirable magnetic characteristics. The nature of the particle alignment is discussed extensively in the section of this report concerned with magnetic property analysis of the recording tapes. It is seen clearly using both the results of the magnetic analysis techniques and SEM micrographs of the recording tape surfaces that an "aligned" tape involves a wide angular dispersion of particle orientations about the alignment axis. The particles are tightly packed with the binder providing the adhesion between particles and to the mylar base.

A video recording tape is subject to tensile stresses along the long axis of the tape. In addition, the tape is bent around various guide and winding wheels and experiences frictional forces as the coating surface is brought in contact with the spinning head. The recording tape, a highly flexible composite structure, is therefore stressed in tension and bending while the coating side of the tape is simultaneously subjected to rubbing with resulting shear stresses through the thickness of the tape material. During normal recording or play-back operations, these mechanical stresses are applied to particular sections of a recording tape intermittently. The normal operating conditions for a recording tape also include a range of environmental parameters such as variable ambient temperatures, humidity and, atmospheric pollutants. The storage environment of a recording tape can be critical for many applications since the factors determining long term durability of the polymeric material configurations in a tape are time and environment sensitive.

The primary goal of the durability phase of these investigations has been to increase the basic understanding of mechanical degradation mechanisms which occur in video recording tape structures. The particular degradation mechanisms investigated during the course of this program were based on the mechanical stress modes involved with play-back and recording processes. Several instruments of the Micromechanics and Magnetics Laboratories at Georgia Tech were employed to accelerate some of the micromechanical mechanisms induced by these stress modes in order to discover and evaluate relevant degradation processes under reasonably defined stress conditions.

The scope of the research tasks selected for the investigations was limited to a small part of the overall capabilities of these laboratories due to the magnitude and duration of the program. However, the application of several of the unique instrumentation systems in these two laboratories to magnetic recording tape investigations resulted in fundamental data which we feel provide new and improved insights concerning several aspects of the performance of these materials.

The experimental techniques and instrumentation employed for these investigations have been described in detail in three quarterly progress reports. The micromechanical investigations on video recording tape materials included the following:

A. Microtensile measurements at both low and high strain magnitudes were conducted on a number of different TDK recording tape materials. Stress rates were varied for these materials and mechanical hysteresis was measured as a function of stress rate. The mechanical characteristics of the magnetic coating materials alone were evaluated by carefully stripping the coatings from the mylar base of measured tensile specimens and comparing the mechanical properties of the composite and base. The elastic moduli of the coatings were significantly higher than those of the mylar base for all the tapes studied. For some types of tape, the elastic modulus of the coating was about four times that of the base material. In most cases, the load supported by the coating in low strain tensile tests was about the same magnitude as that supported by the base even though the thickness of the base is about three times that of the coating. Simple exposure of the coating material to high humidity for several days decreased significantly the elastic modulus of the coating material but not that of the base.

B. Friction investigations were carried out on TDK tape specimens with the low load friction apparatus using both stainless steel and recording head elements as styli. Quantitative measurements were made on the detailed stick-slip characteristics of these tape materials at load pressures corresponding to those estimated for video tapes on the head. A few friction specimens were exposed to 100% R. H. for several days. Average friction coefficients both increased and decreased, depending upon the type of tape medium. However, significant alterations in the stick-slip details were noted in each case.

C. Accelerated wear tests were carried out on a number of different tape specimens using both stainless steel and recording head materials as styli. Wear track measurements using both profilometer traces and SEM micrographs revealed interesting details concerning wear mechanisms.

D. In situ SEM coating crack initiation measurements were carried out on the TDK tape specimens. These showed that incipient cracks generally occur at specimen strains between 1% and 4%.

The accelerated testing or overstressing of video recording tape specimens using the techniques outlined above provided data concerning potential micromechanical degradation mechanisms in the tape materials. The tensile measurements show a high elastic modulus of the coating material relative to that of the base material. The magnetic coating material is a composite structure somewhat analogous to the short fiber reinforced composites employed in high performance structural applications. While the coating materials are primarily designed to meet magnetic parameter performance objectives, they do share in providing about half of the tape's tensile strength at the low strain levels experienced during normal recording and play-back operations. However, the coating material is far more brittle than is the mylar base; incipient microcracks occur in the coating structures at strain levels as low as 1%.

The initial appearance of these incipient cracks probably does not alter the magnetic performance of the tape for video purposes since the in situ SEM observations show only very minor displacements of the magnetic particles. The smallest cracks generally close completely as the mechanical stress is relaxed. Multiple tensile stress and rubbing cycles will cause growth of these cracks as a complex form of mechanical fatigue damage to the coating structures.

The results of this work permit us to propose mechanisms to account for the mechanical degradation of video recording tapes after extended usage. The recent in situ SEM observations of stressed tape specimens provided visual evidence to support these degradation models. These data are summarized in the following paragraphs with supporting curves, micrographs and schematic drawings. A scientist concerned with discovering degradation mechanisms, rather than a skilled SEM operator, operated the EM during the various in situ crack initiation investigations. Therefore, some of the micrographs illustrating coating microstructures could be better.

The SEM micrographs of Figures 1 and 2 show incipient microcracks initiated in TDK tape specimens stressed in situ. The sizes of these cracks are indicated by the dimensions of the acicular particles which are said to be about 1 micrometer in length. These incipient cracks tend to close completely as the

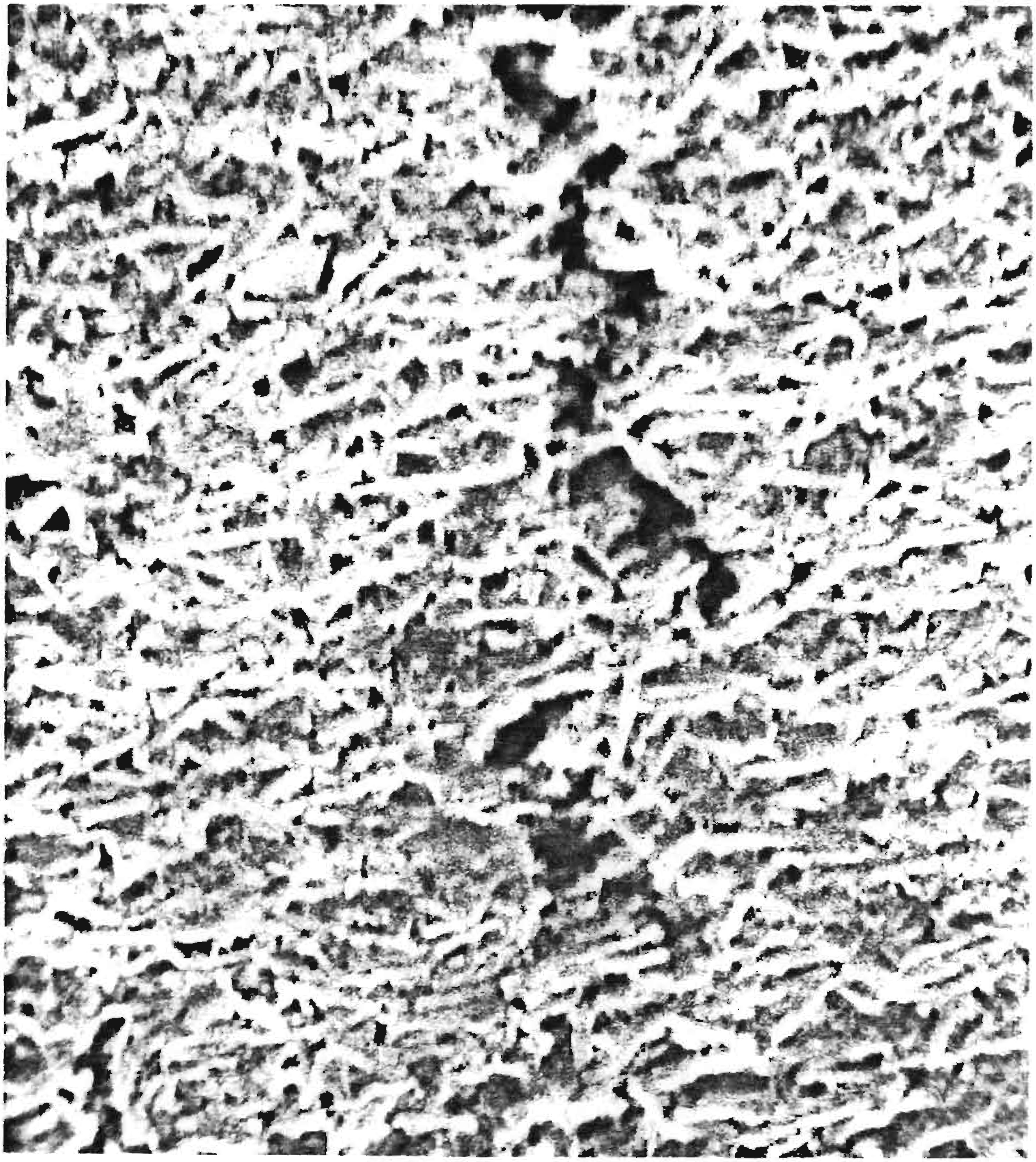

Figure 1. Incipient Crack Noted In TDK Tape Coatings At Low Strain Levels. Magnetic Particles Quoted To Be About 1 micrometer In Length.

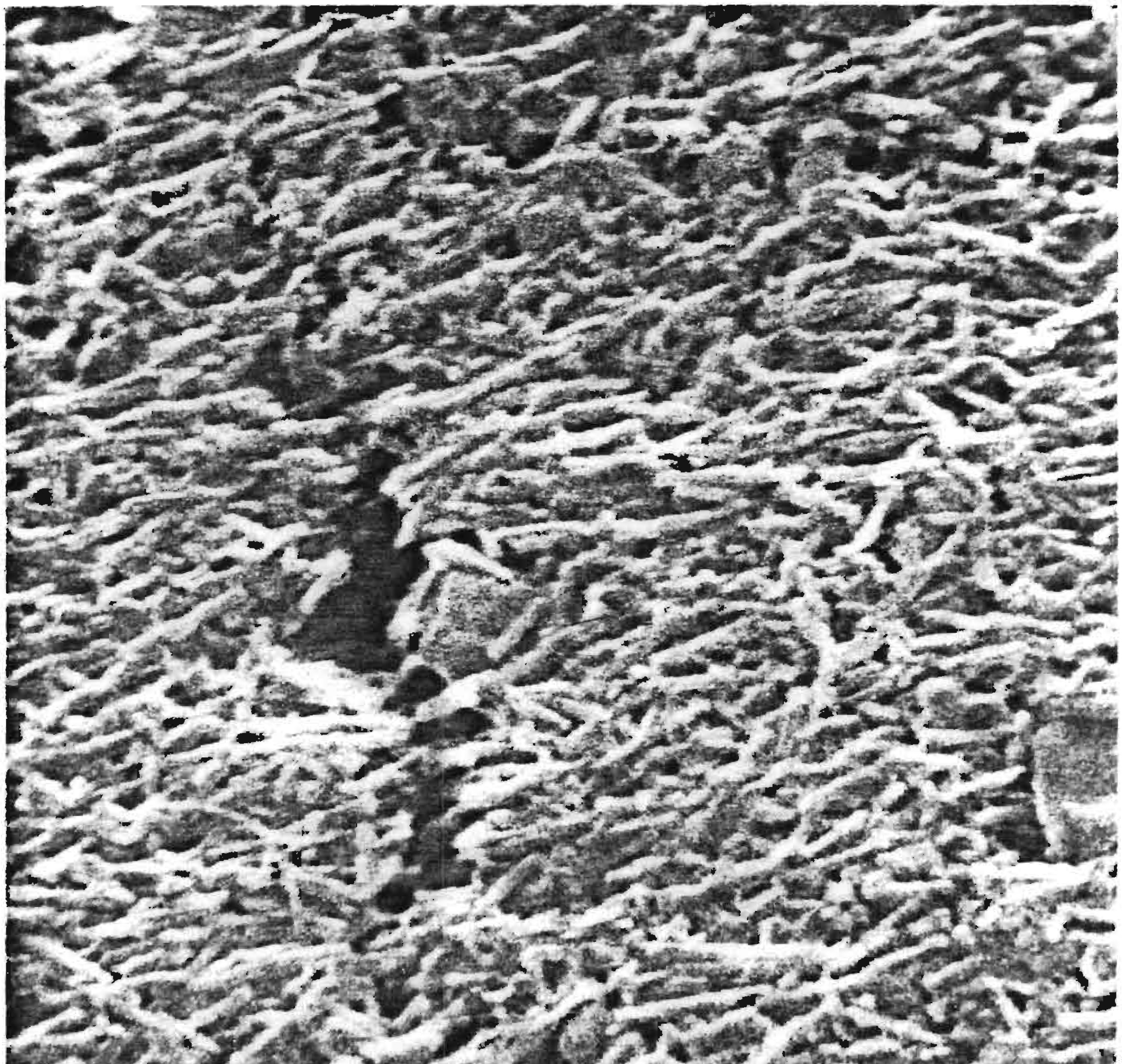

Figure 2. Incipient Crack Noted In TDK Tape Coating At Low Strain Levels. Magnetic Particles Quoted To Be About 1 Micrometer In Length.

applied stress is relaxed such that magnetic performance should not be altered appreciably.

Strains necessary to initiate cracking in several TDK tapes were measured using the in situ stress techniques described in earlier reports. This technique involves the application of markers over the necked-down region of the tape specimens. Careful attention to maintaining the same magnification while taking micrographs of the calibration markers allowed us to use these patterns to measure the actual strain of the tape region being viewed in the SEM. The potential for introducing considerable measurement error with other methods was discussed in the October report.

Strains at crack initiation for five TDK tape specimens are shown below.

TDK TAPE IDENTIFICATION	STRAIN AT INCIPIENT CRACK INITIATION
EV-053-1	1.9 - 2.4%
EV-033-5	1.4 - 1.8%
EV-043-3	3.9%
EV-086-1	2.6%
ADC-212	1.5 - 2.9%

The AOC-212 data are for a different specimen from that reported in the October report where initial cracks were noted as low as 0.6% strain. These data show that measured stresses to failure in brittle materials scatter considerably. Stress concentrations within the specimen, misalignment of specimen grips and other factors can have considerable influence on the observed stresses or stains to fracture. It is desirable to evaluate statistically significant numbers of specimens. However, these measurements are tedious and require long times on the SEM (4-7 hours) for each specimen. Certain instrumentation improvements, including those discussed previously would reduce these times. Incipient cracks can be initiated in the tape coatings at strain levels less than 1%, but they may require about 4%, Figures 3-8 are load-strain curves taken in air of TDK tensile specimens for the strain values involved in incipient crack initiation. The crack initiation values should be correlated with the corresponding load-strain data.

The observation of mechanical degradation mechanisms is the most valuable aspect of the in situ, SEM stressed tape studies. The progress of a crack propagation, observed repeatedly in stressed tapes, is shown in Figures 9-14. Microcracks, which

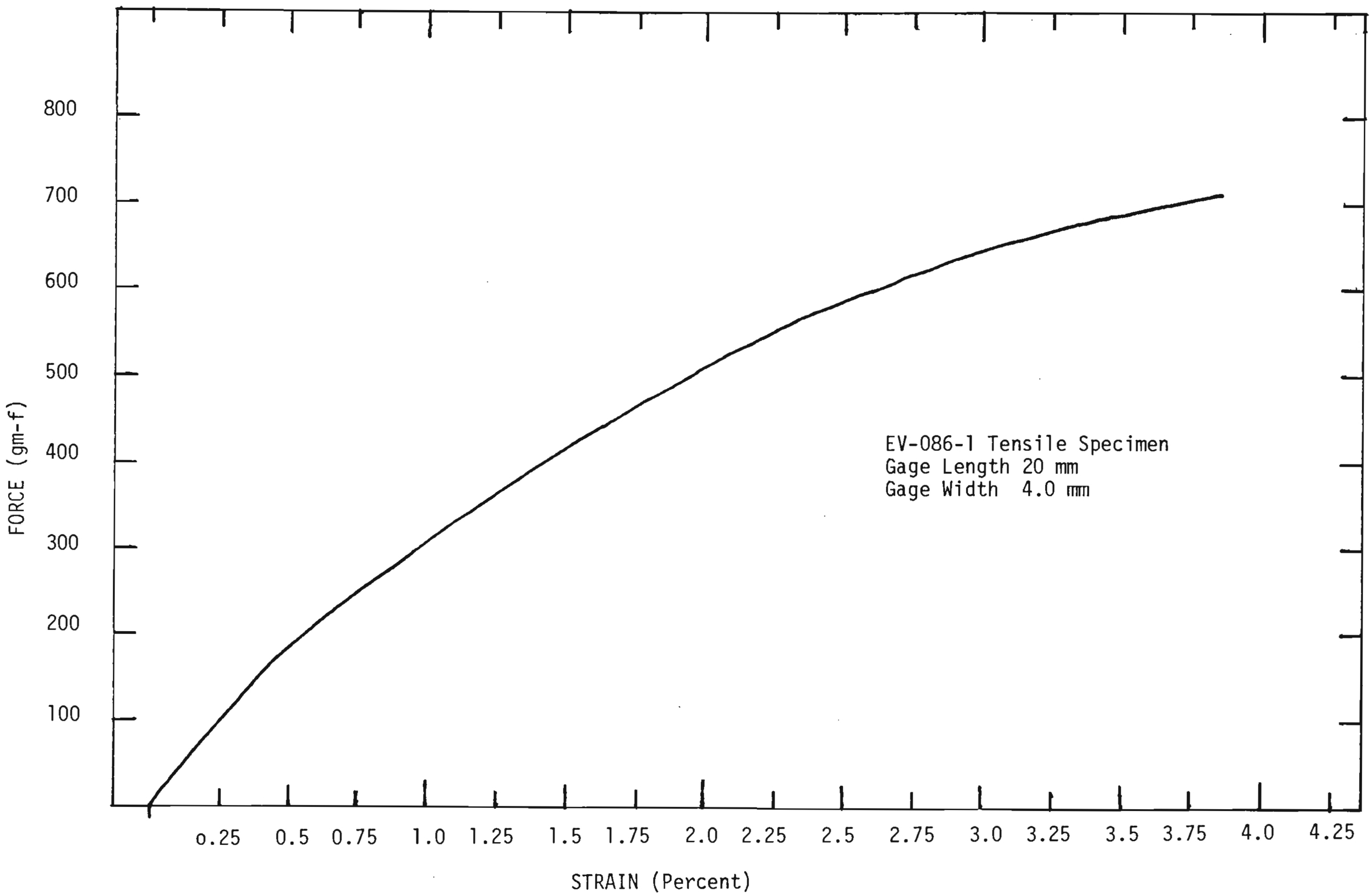

FIGURE 3. Stress-Strain Behavior For EV-086-1 Tensile Specimen

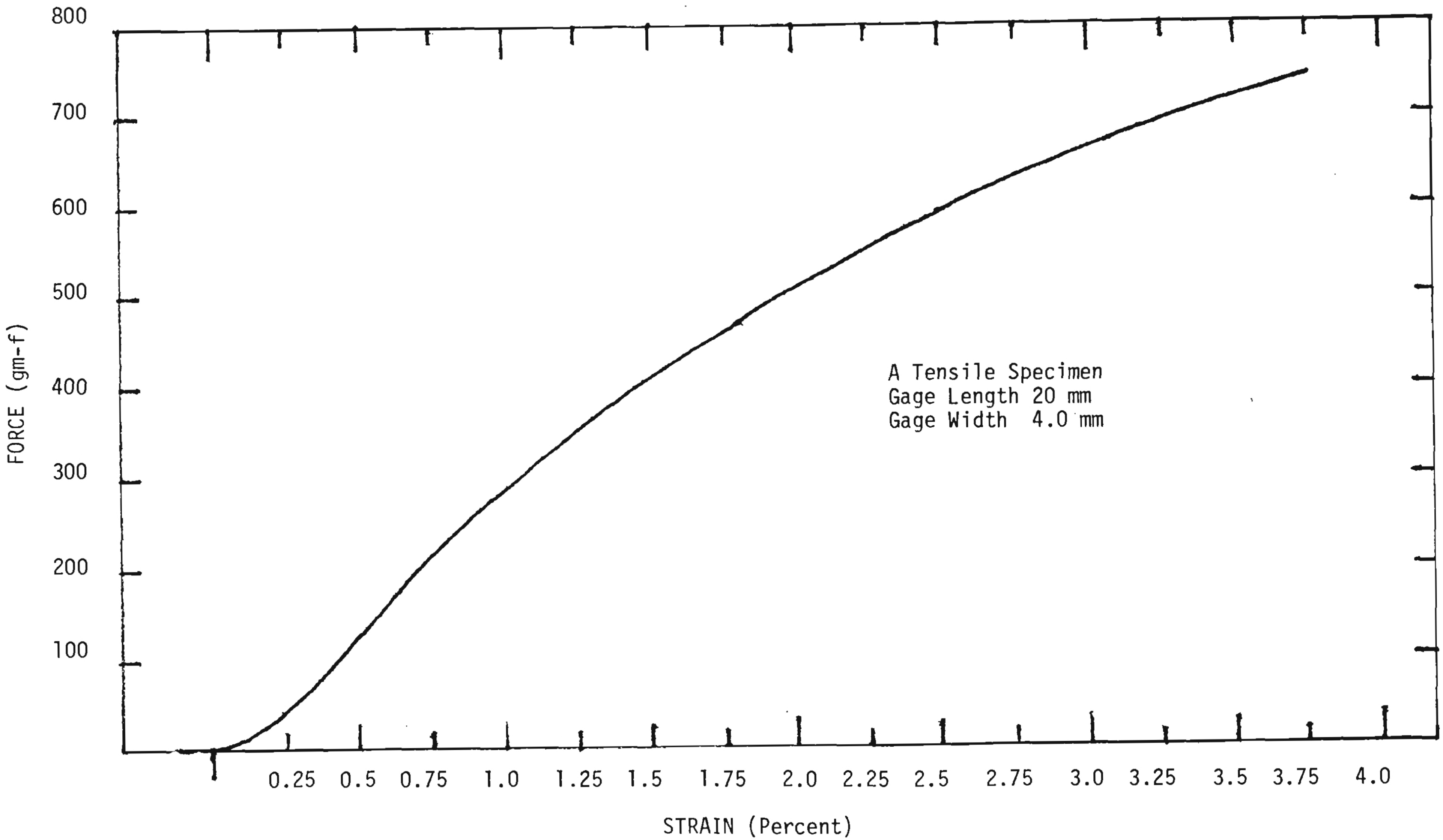

FIGURE 4. Stress-Strain Behavior For A Tensile Specimen

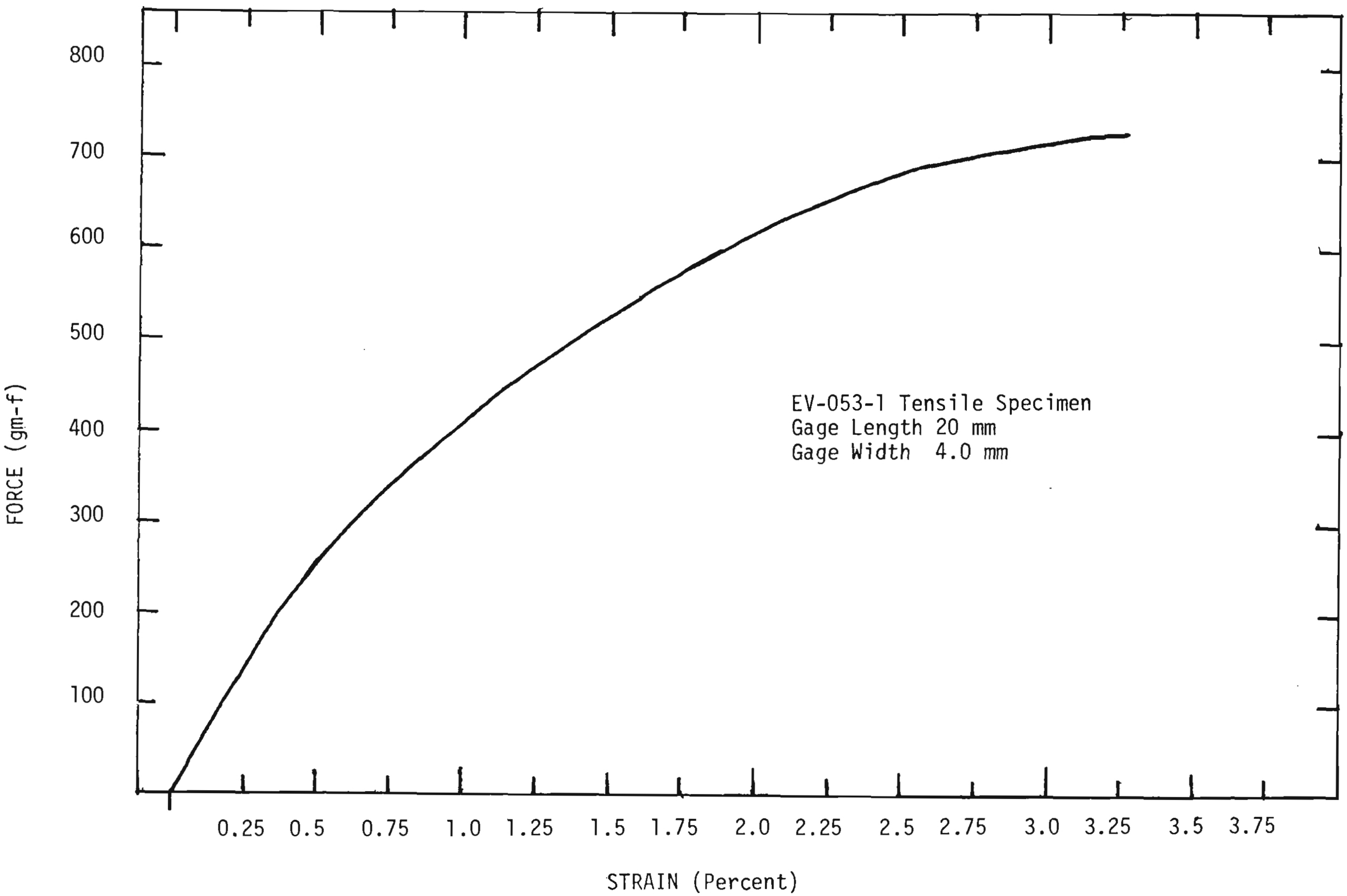

FIGURE 5. Stress-Strain Behavior For EV-053-1 Tensile Specimen

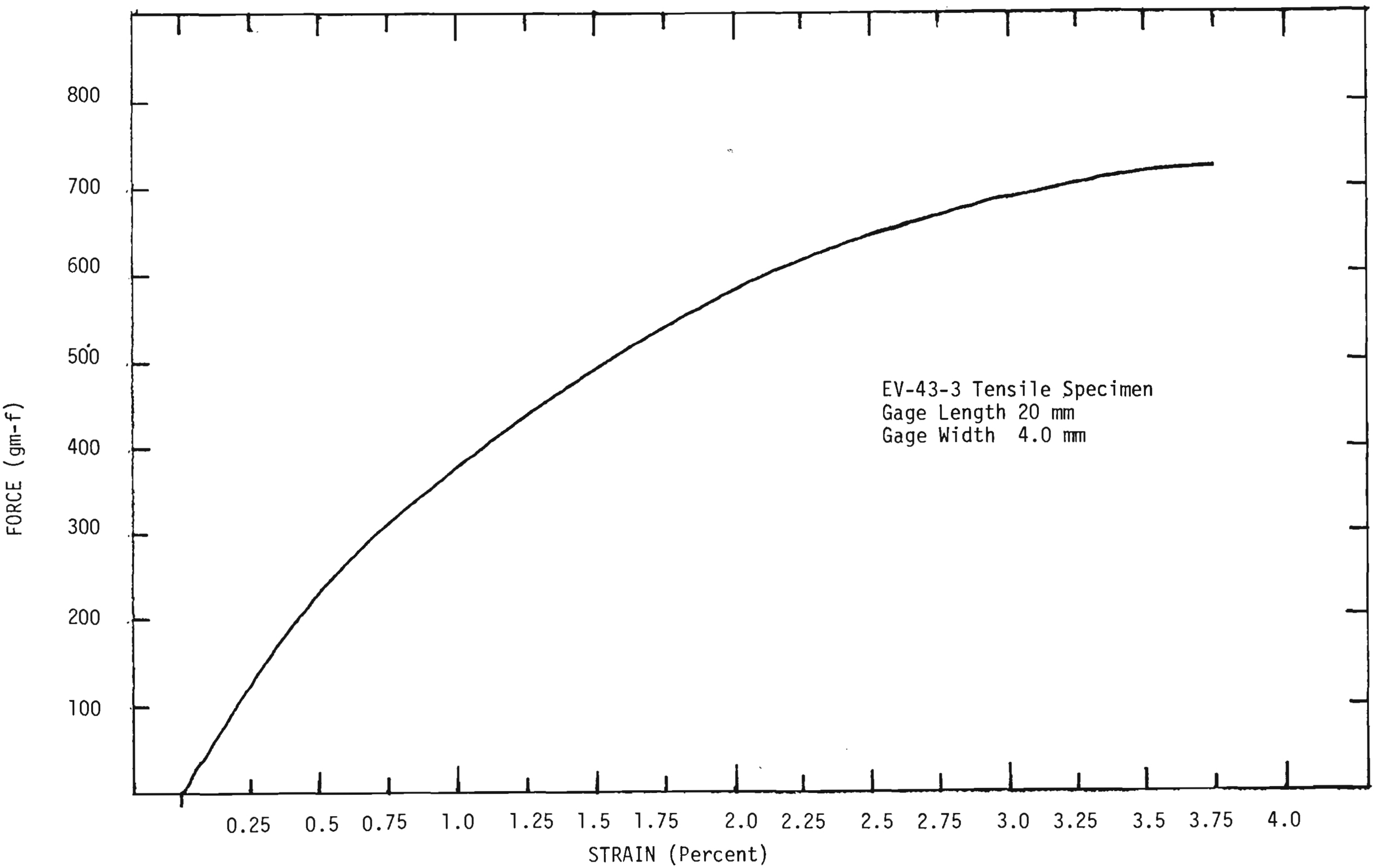

FIGURE 6. Stress-Strain Behavior For EV-43-3 Tensile Specimen

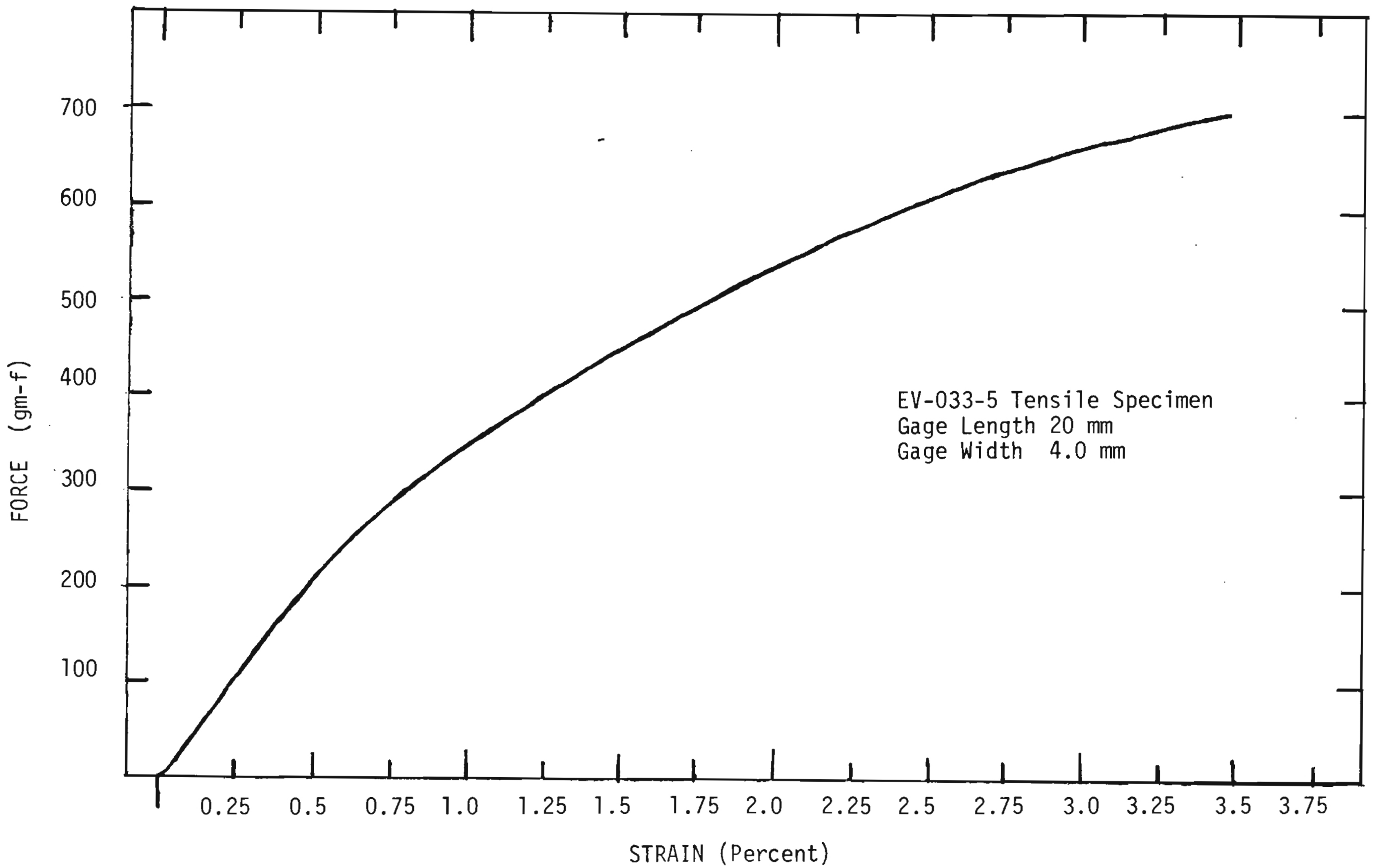

FIGURE 7. Stress-Strain Behavior For EV-033-5 Tensile Specimen

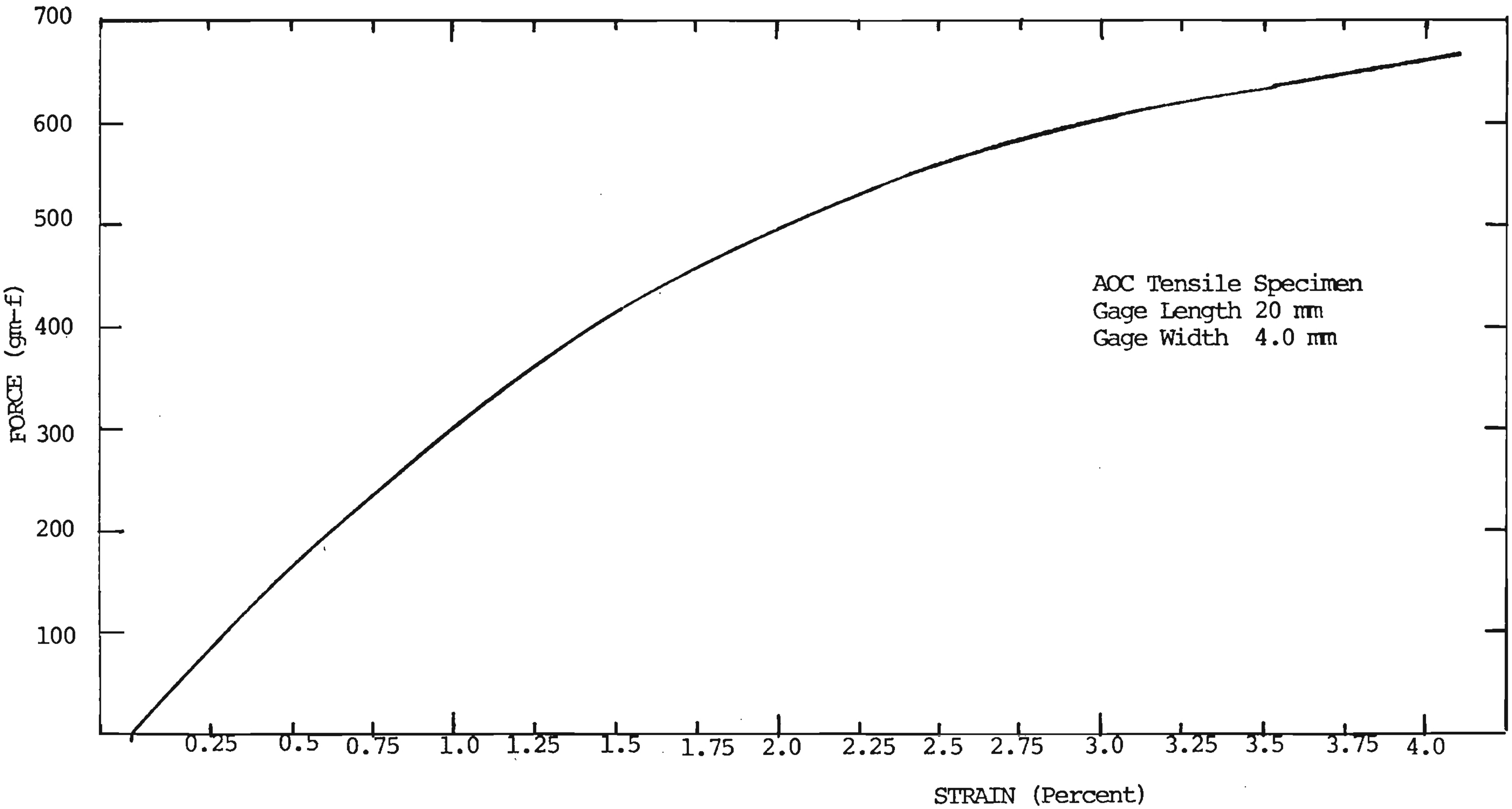

Figure 8. Stress-Strain Behavior For AOC 212 Tensile Specimen

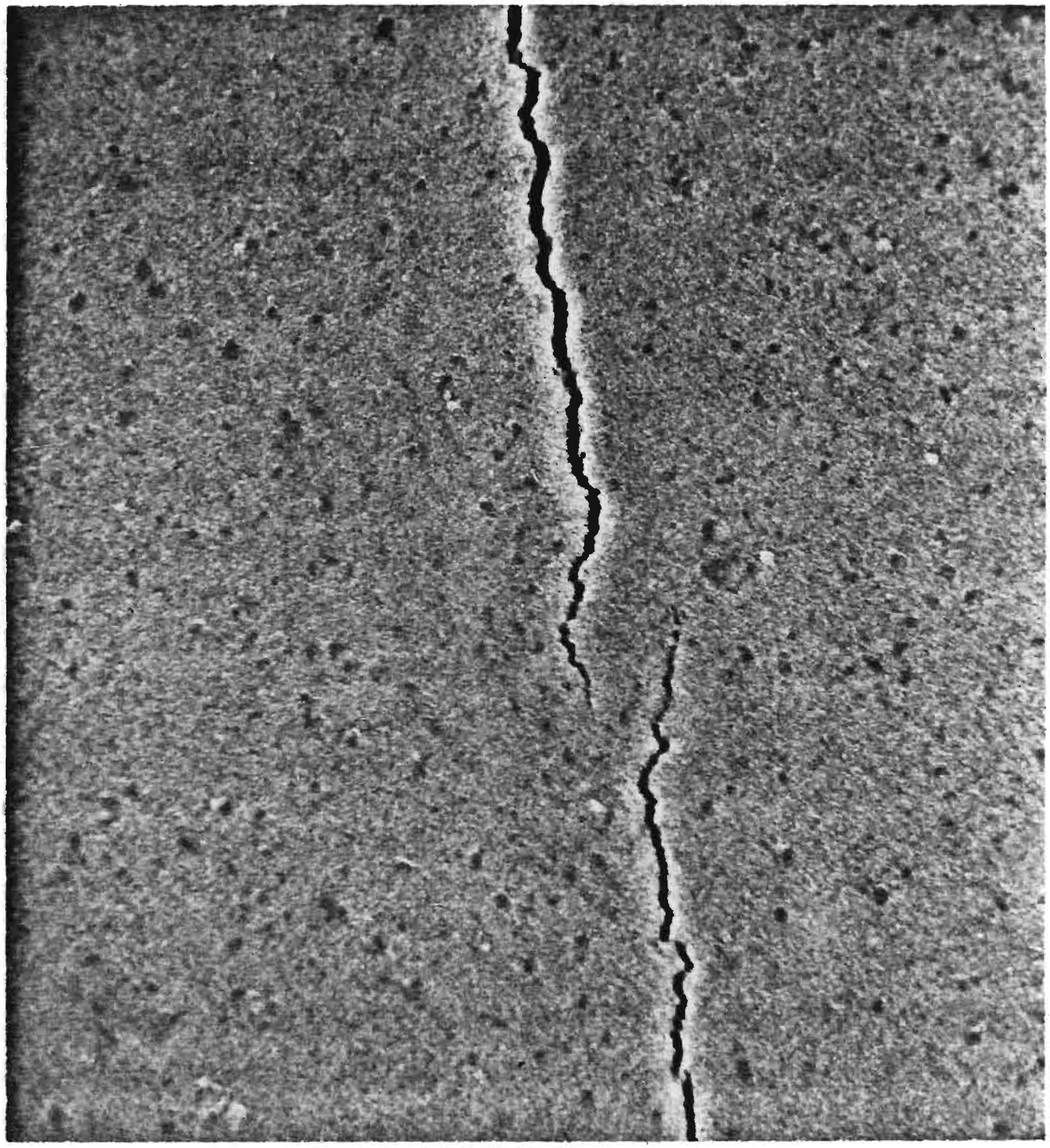

Figure 9. SEM Micrograph Showing Parallel Neighboring Cracks In Coating Of TDK Type EV-033-5 Recording Tape Stressed And Observed In Situ In An SEM. The Stress Axis Is Horizontal With Cracks Shown Propagating Perpendicular To The Stress Axis. 2,600X.

Figure 10. SEM Micrograph Showing Crack Pair Of Figure 9 After Increased Strain. 2,600X.

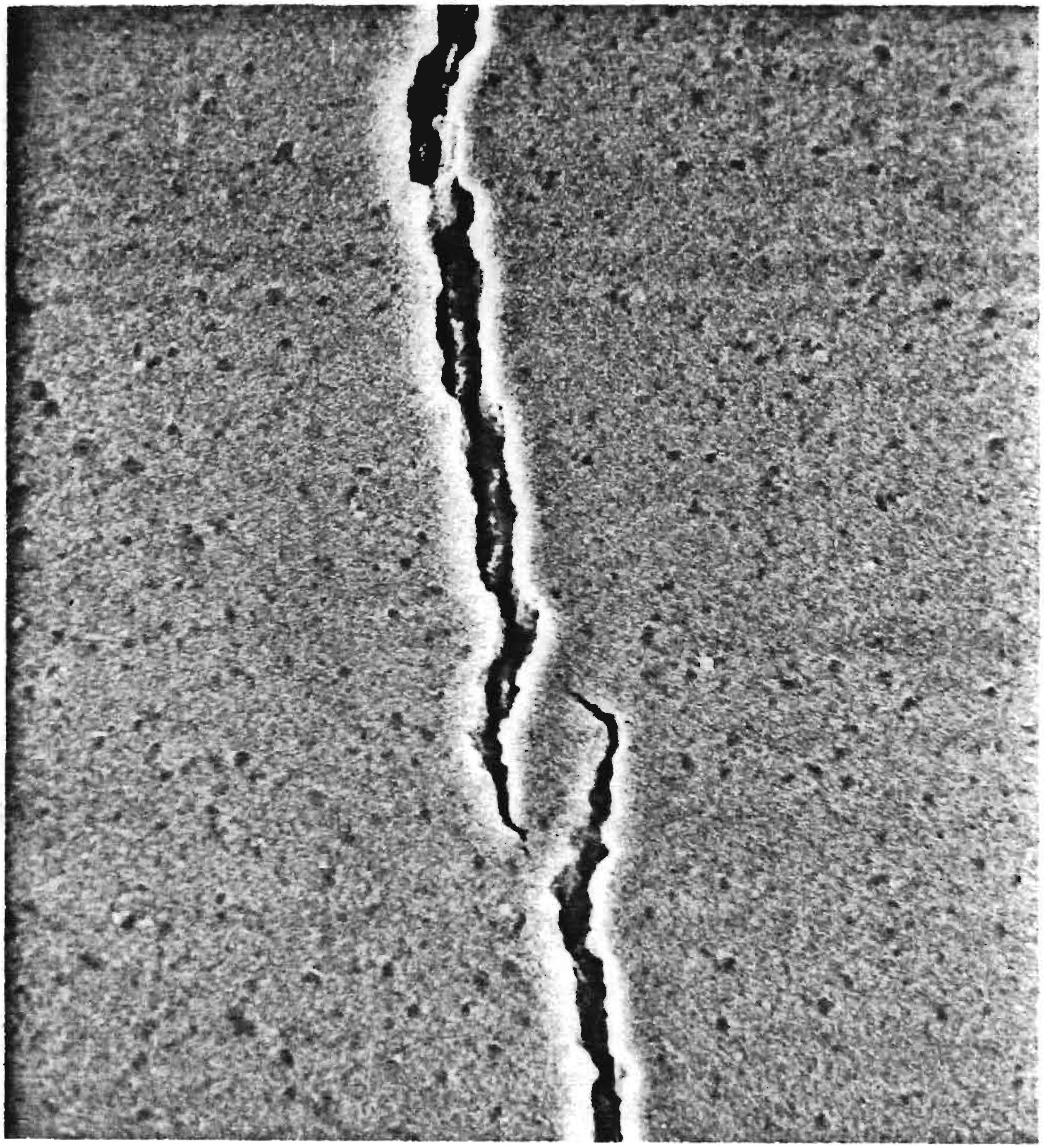

Figure 11. Cracks Of Figure 9 At Still Greater Strain. 2,600X.

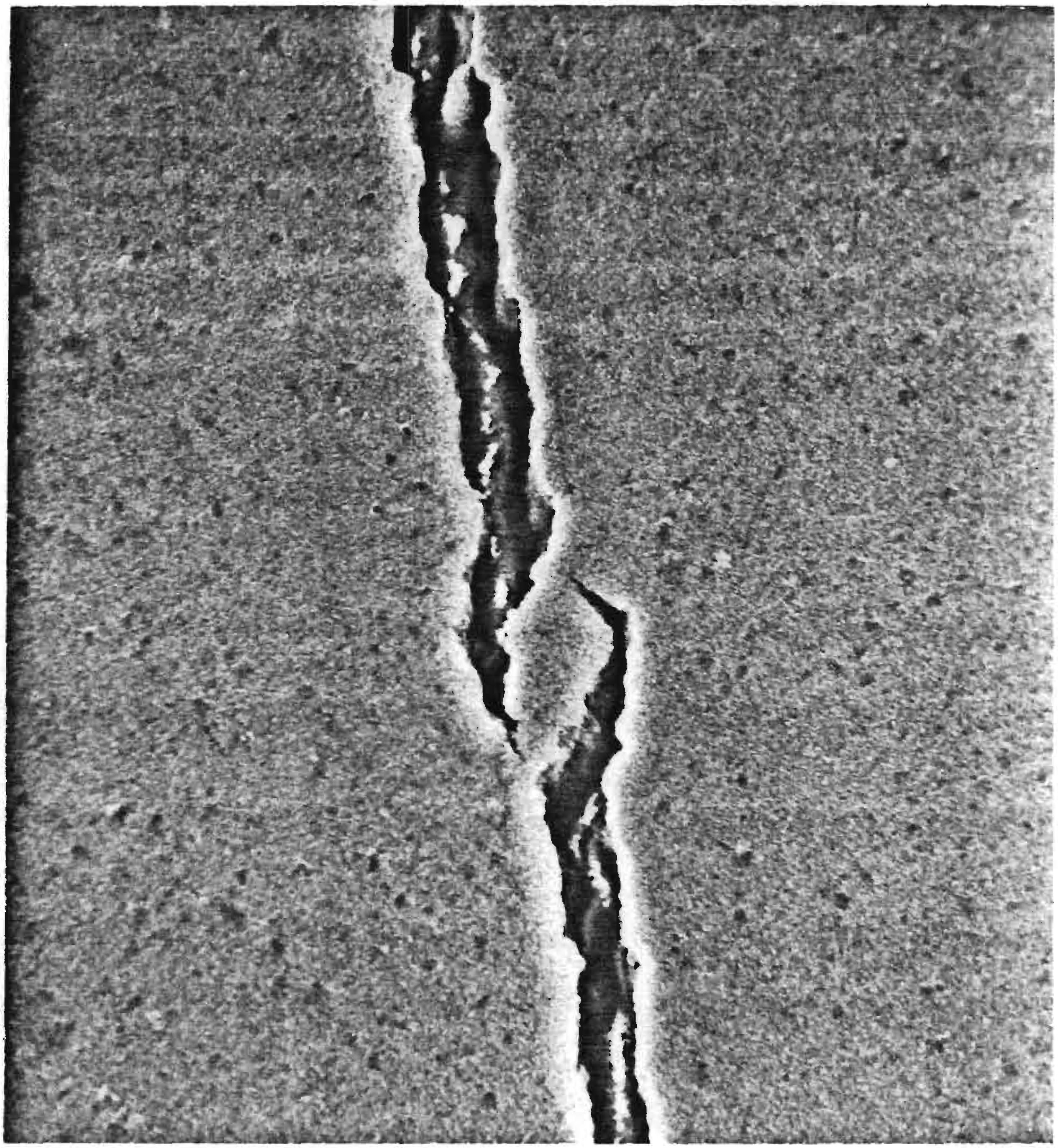

Figure 12. Cracks Of Figure 9 At Still Greater Strain. 2,600X.

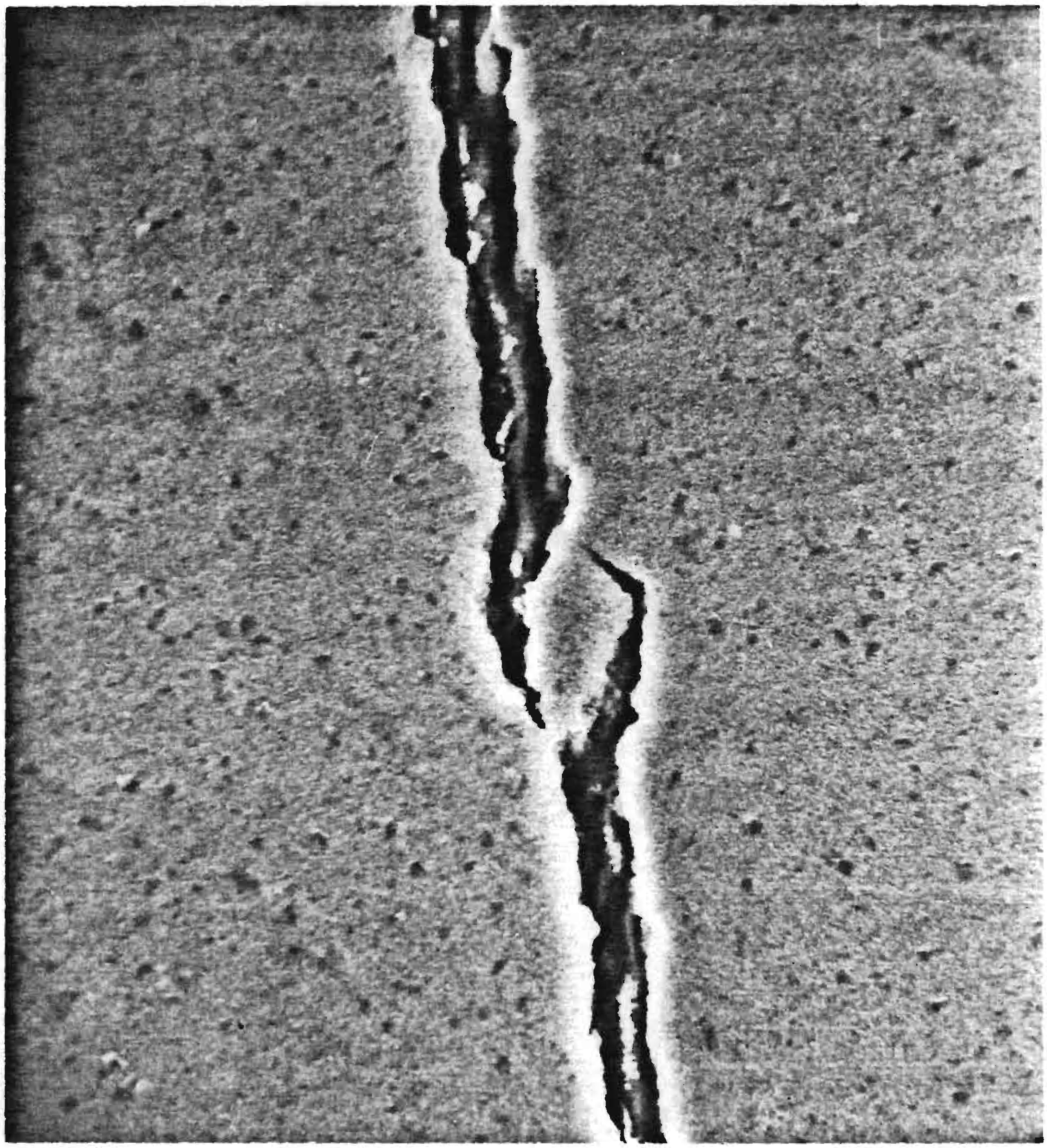

Figure 13. Cracks Of Figure 9 At Same Strain As For Figure 12 But After Four Complete Stress-Stress Relaxation Cycles. 2,600X.

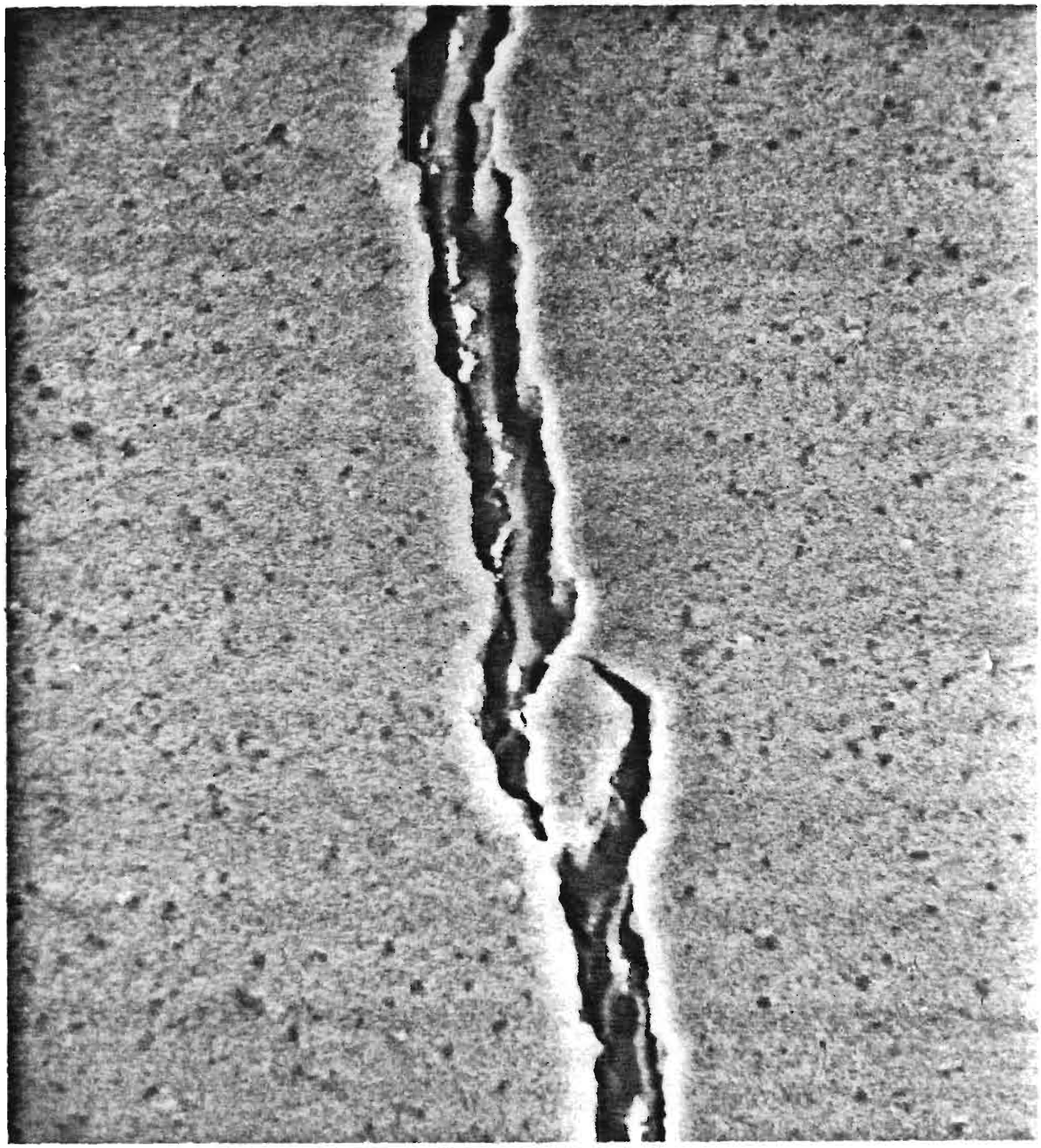

Figure 14. Cracks Of Figure 9 At Same Strain As For Figure 12 But After Eleven Complete Stress-Stress Relaxation Cycles. 2,600X.

form in recording tapes stressed along the tape axes, always grow perpendicular to the stress axis. As leading edges of parallel cracks approach one another the directions of the cracks tend to first diverge slightly apart and then converge towards neighboring cracks. This process is shown schematically in Figure 15. Micrographs of crack growth patterns as stress in increased are shown in Figures 9-14. Crack growth due to mechanically cycling tape specimens from zero to the previous strain level 4 and 11 times, respectively, is shown in Figures 13 and 14.

A similar sequence of micrographs for an EV-043-3 type tape specimen is shown in Figures 16-21. Figure 16 shows the crack configuration while stress is applied and Figure 17 is for the stress relaxed. Figure 18 is a micrograph of the crack after being restressed to the same value and Figure 19 is after the 5th cycle. Figure 20 is for still higher strain while Figure 21 illustrates the creation of a separated fragment of the coating material. Note that Figure 20 shows that still a third microcrack interacted similarly with the upper end of the upper member of the crack pair shown in Figure 16 to generate another potential coating fragment at their intersection.

We have seen numerous examples of this mechanism, including that in Figures 9 and 10 of the October report. Such fragments

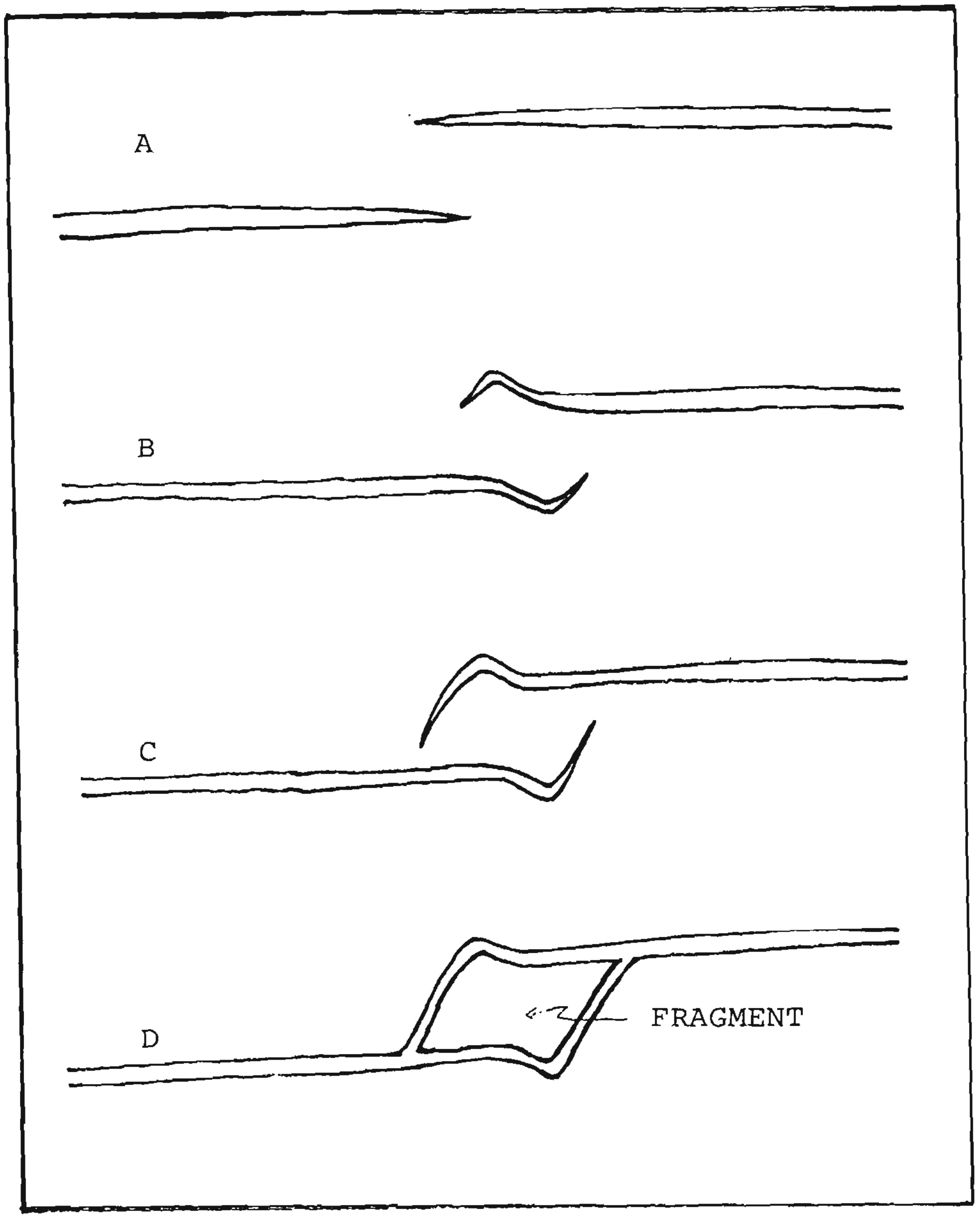

Figure 15. Schematic Representations Showing How The Leading Edges Of Two Parallel Microcracks In A Tape Coating Are Deflected First Away From And Then Towards The Neighboring Crack. Coating Material Outlined By The Joined Cracks May Subsequently Become Separated From The Base As A Fragment.

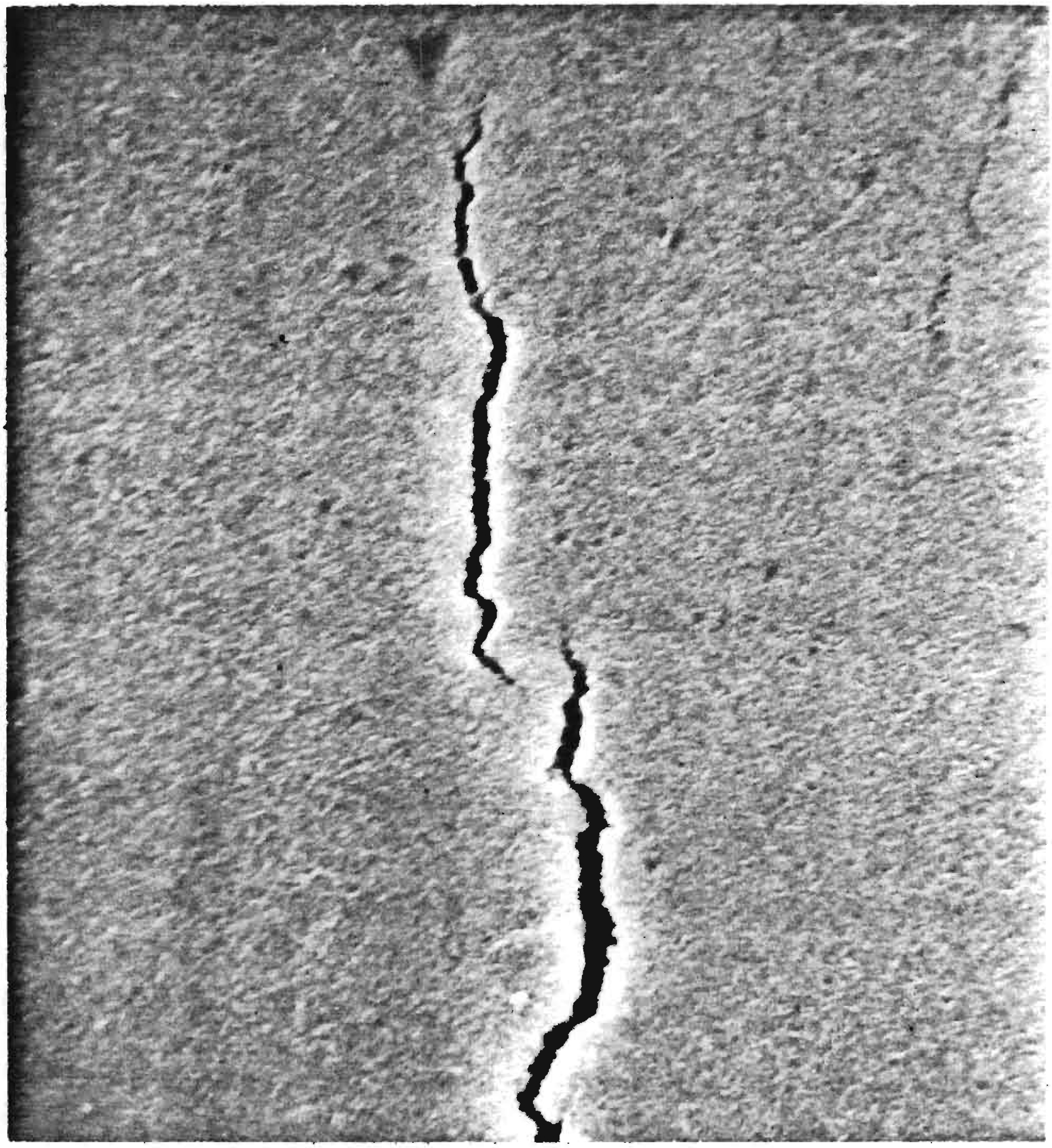

Figure 16. SEM Micrograph Of Parallel Cracks In Coating Of TDK Type EV-043-3 Recording Tape Specimen Stressed And Observed In Situ In An SEM. The Stress Axis Is Horizontal. 5,280X.

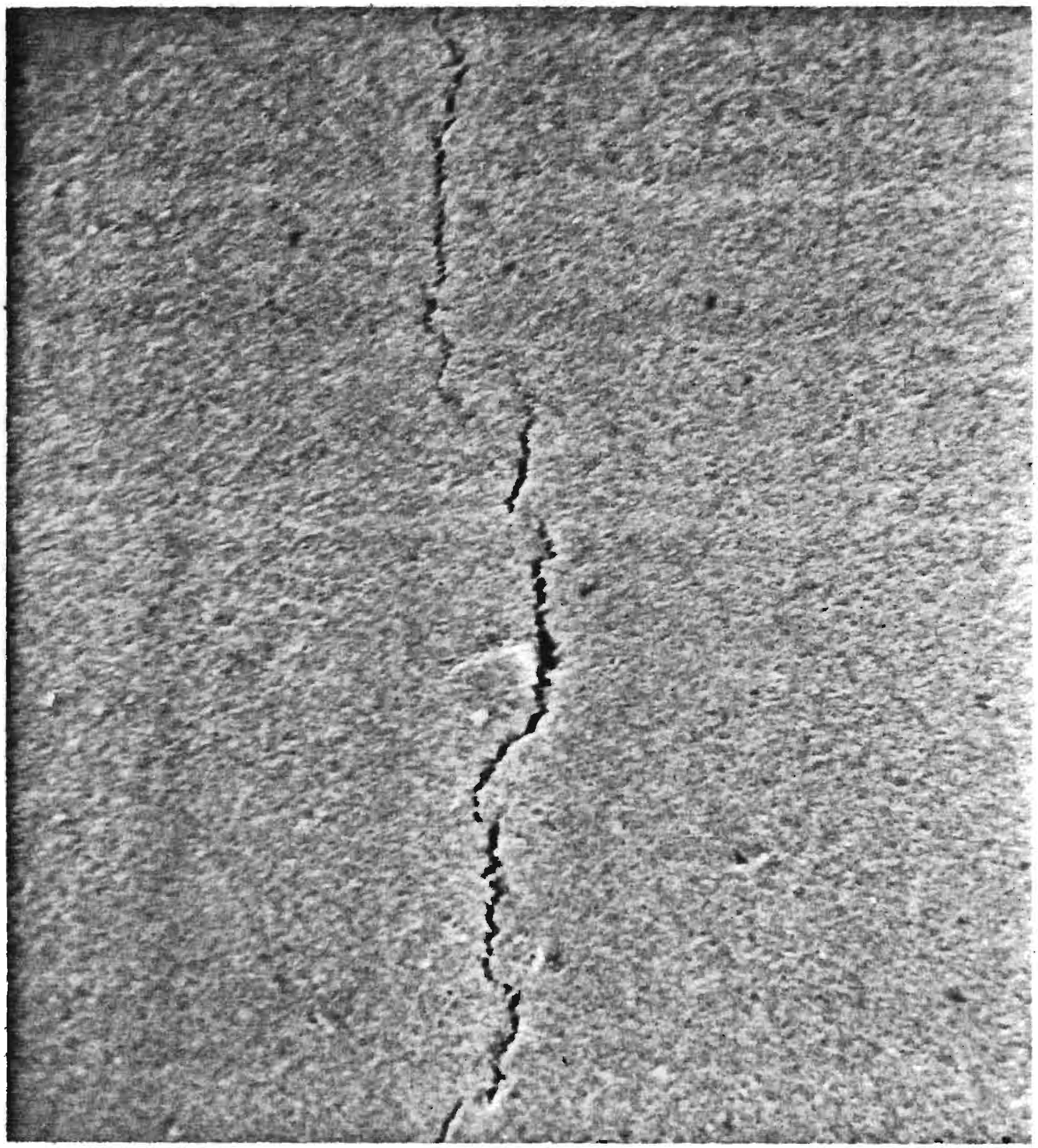

Figure 17. Cracks Of Figure 16 Shown With Stressed Relaxed. Note That A Crack Of This Size Did Not Completely Close When The Stress Was Removed. 5,280X.

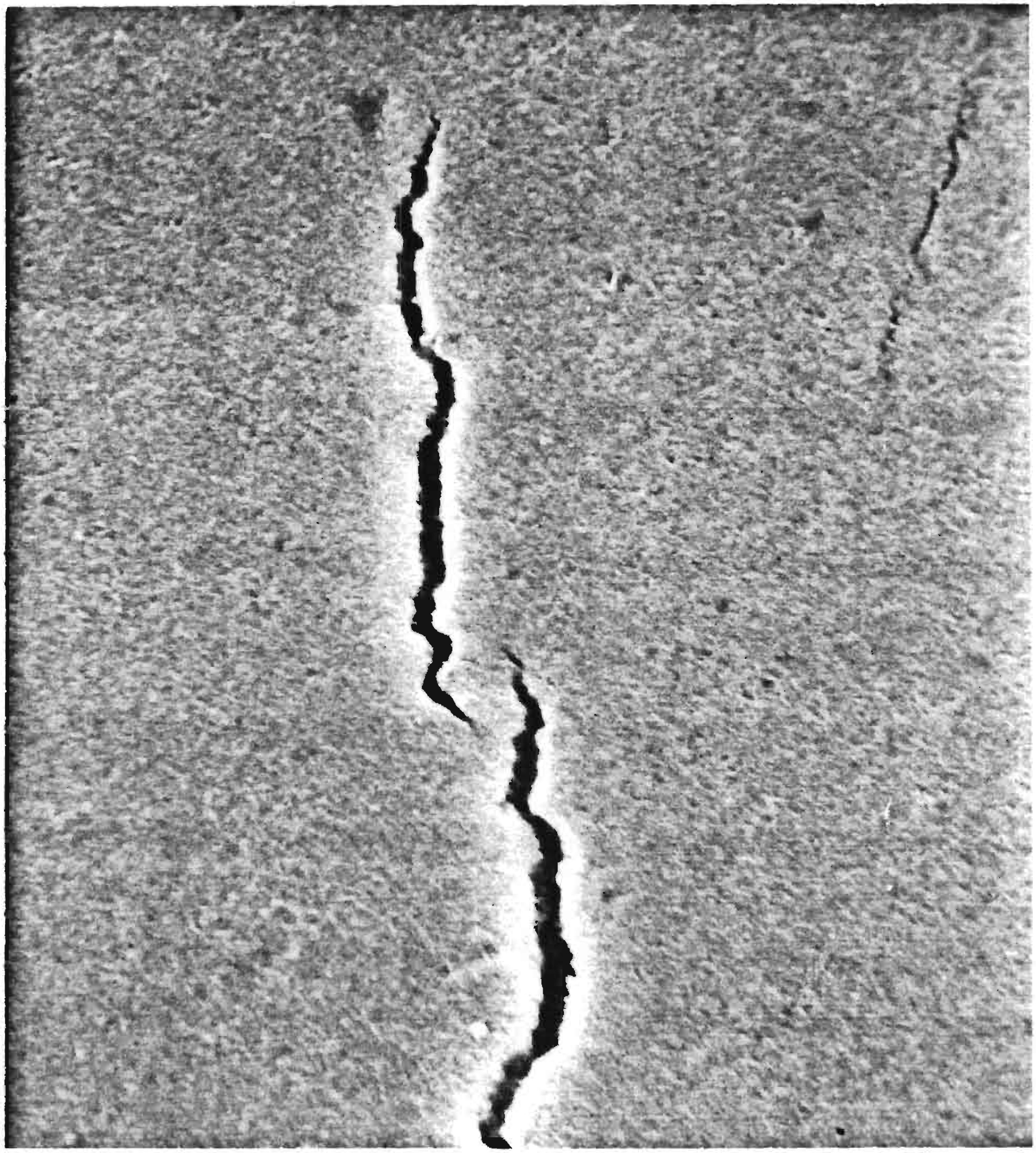

Figure 18. SEM Micrograph Showing Cracks Of Figure 16 After Reapplication of Stress. 5,280X.

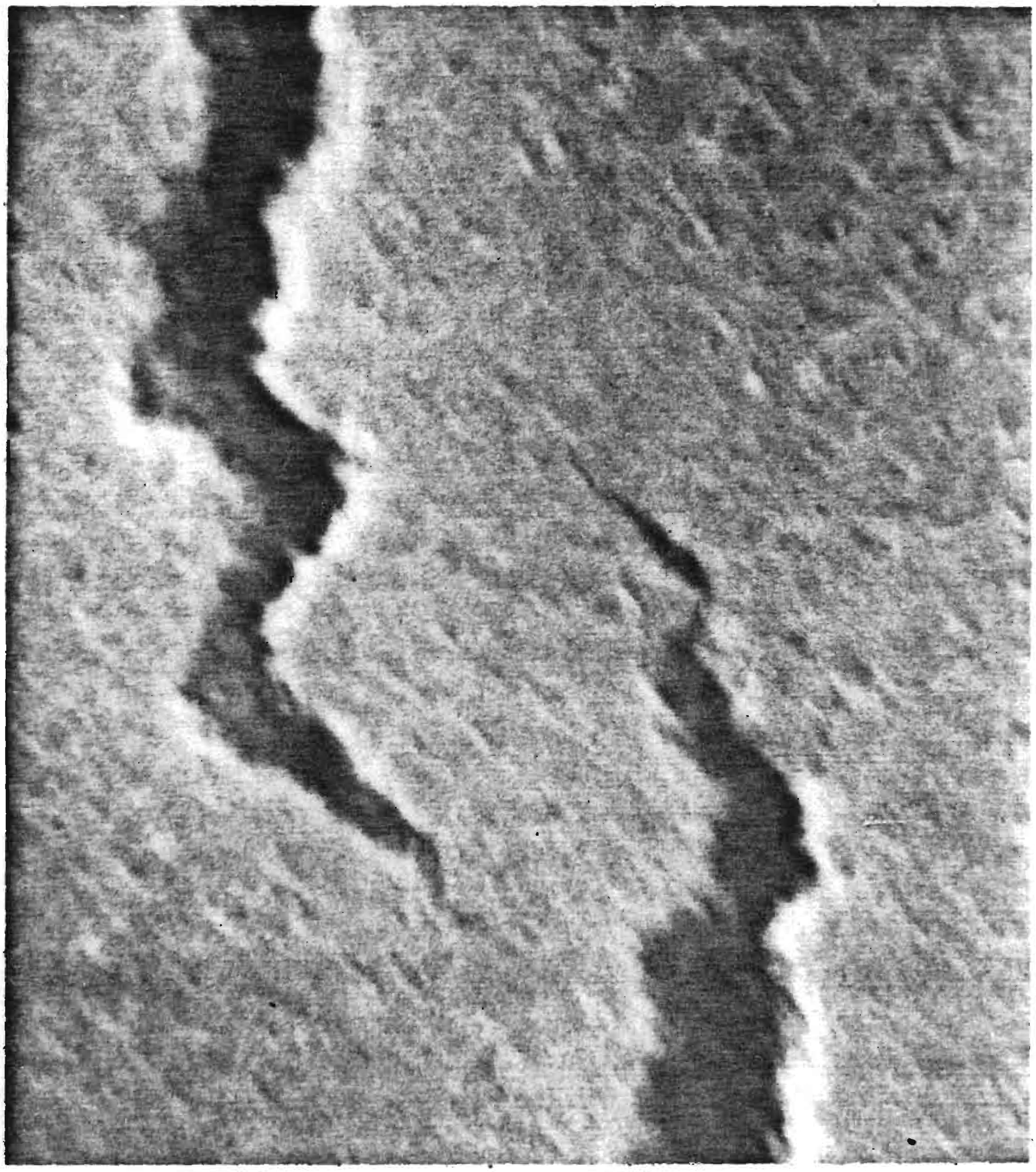

Figure 19. SEM Micrograph Showing Cracks Of Figure 16 At Same Strain Level As For Figure 18 But After Five Complete Stress-Stress Relaxation Cycles. 26,300X.

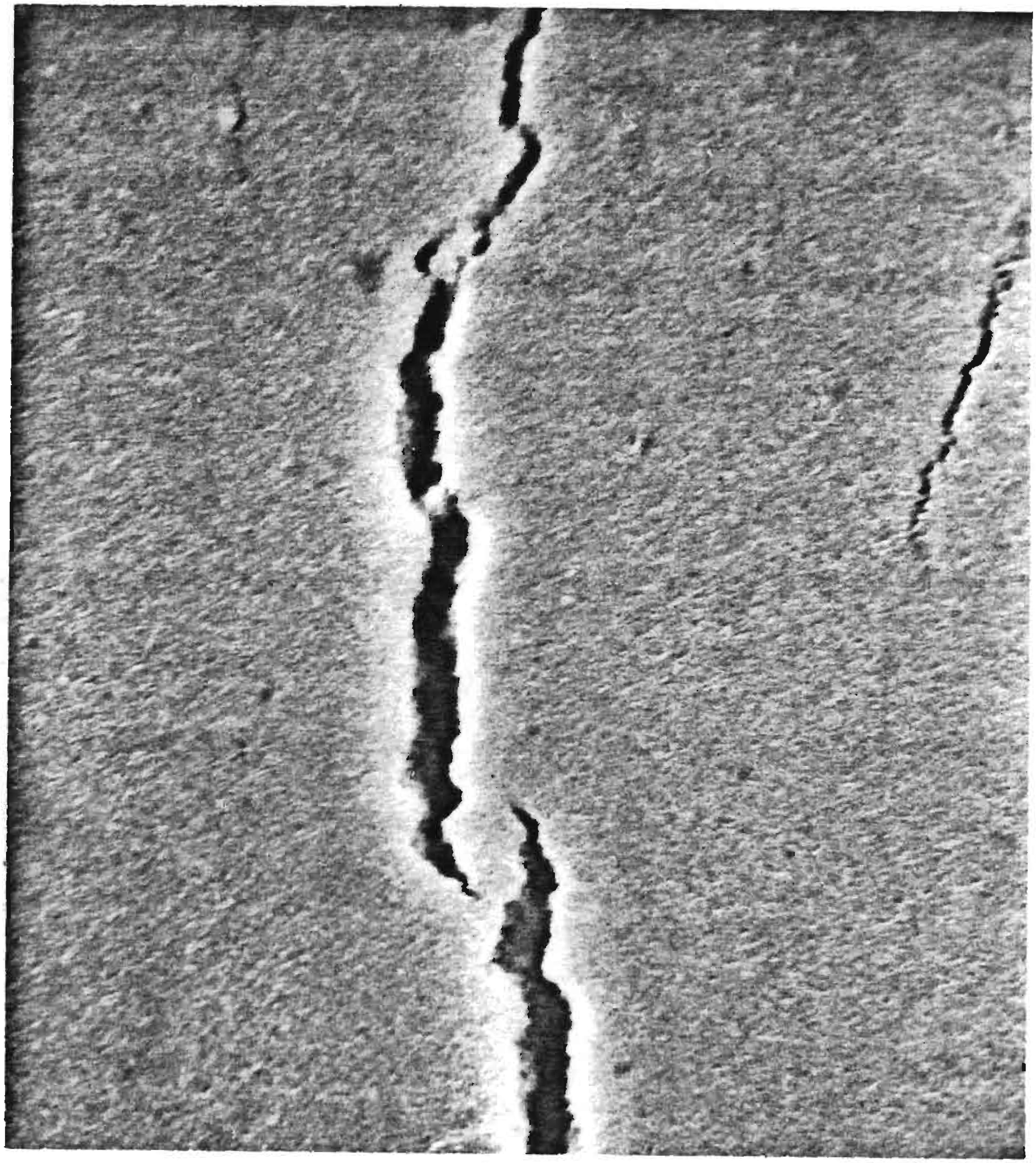

Figure 20. SEM Micrograph Showing Cracks Of Figure 16 At Strain Increased From That For Figure 19. By Comparing The Upper Edge Of This Micrograph With Figures 16 and 18 One can See Where A Third Microcrack Has Intersected With The Upper End Of The Upper Crack To Produce Another Potential Loose Fragment. 5,280X.

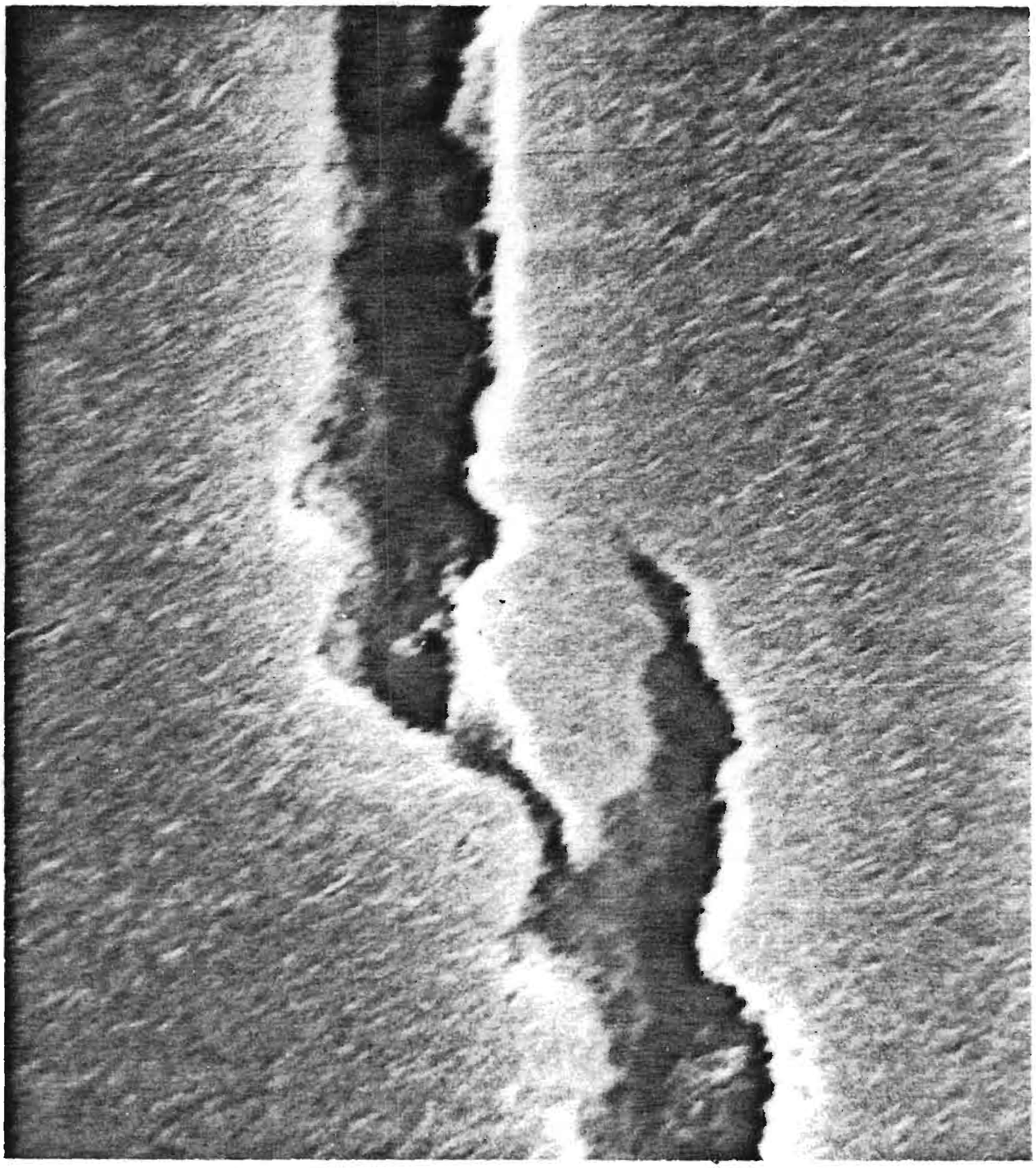

Figure 21. SEM Micrograph Showing Where Completion Of The Intersection Of The Two Parallel Cracks Initially Shown In Figure 16 Has Resulted In A Potential Loose Fragment From The Magnetic Coating. The Strain Had Been Further Increased And Then Relaxed Prior To Taking This Micrograph. 13,400X.

will be ejected from the tape coating due to the combined flexure and shear stresses from rubbing and represent an advanced stage of wear.

The edges of cracks tend to elevate slightly as strain increases. An exaggerated example of this phenomenon is shown in Figure 22. These observations indicate that the bond between the coating and base materials immediately adjacent to the cracks fails as illustrated in Figure 23. The significance of early stages of this adhesive breakdown is shown schematically in Figure 24. Even slightly elevated coating material at the crack edge may be fracture as the tape passes the head, creating a loose fragment of abrasive magnetic material.

These mechanisms for generating magnetic fragments are combined with the apparent prow formation discussed in a previous report. A schematic diagram showing exaggerated formation of a prow is provided in Figure 25. The evidence for material transfer by prow formation was provided in earlier wear pattern micrographs as shown in Figure 26.

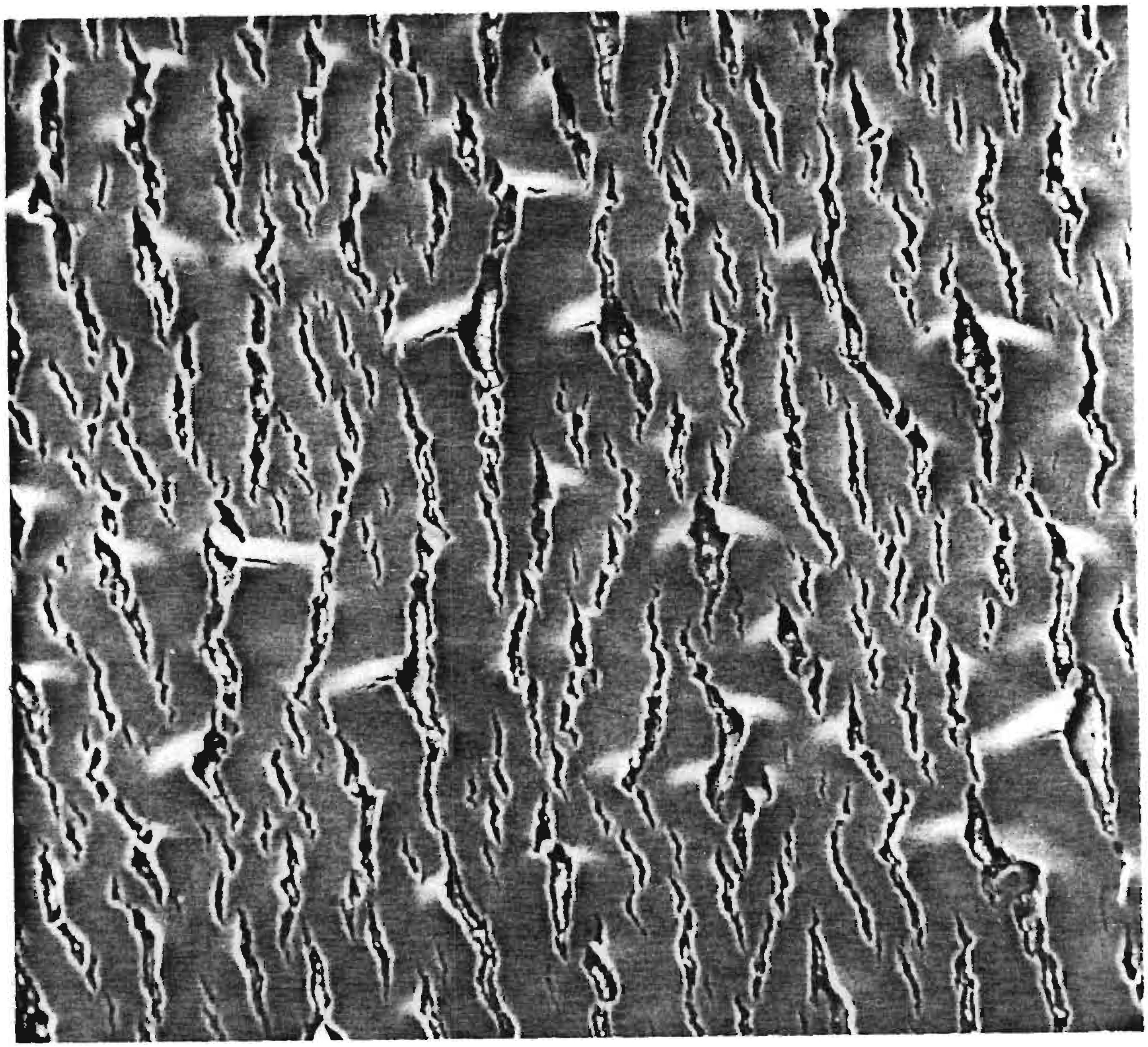

Figure 22. SEM Micrograph Showing The Many Cracks In A TDK Tape Specimen Highly Strained Using The In Situ Stress Device. Note That The Coating Vaults Above The Plain Of The Tape At The Highly Strained Crack Edges. 281X.

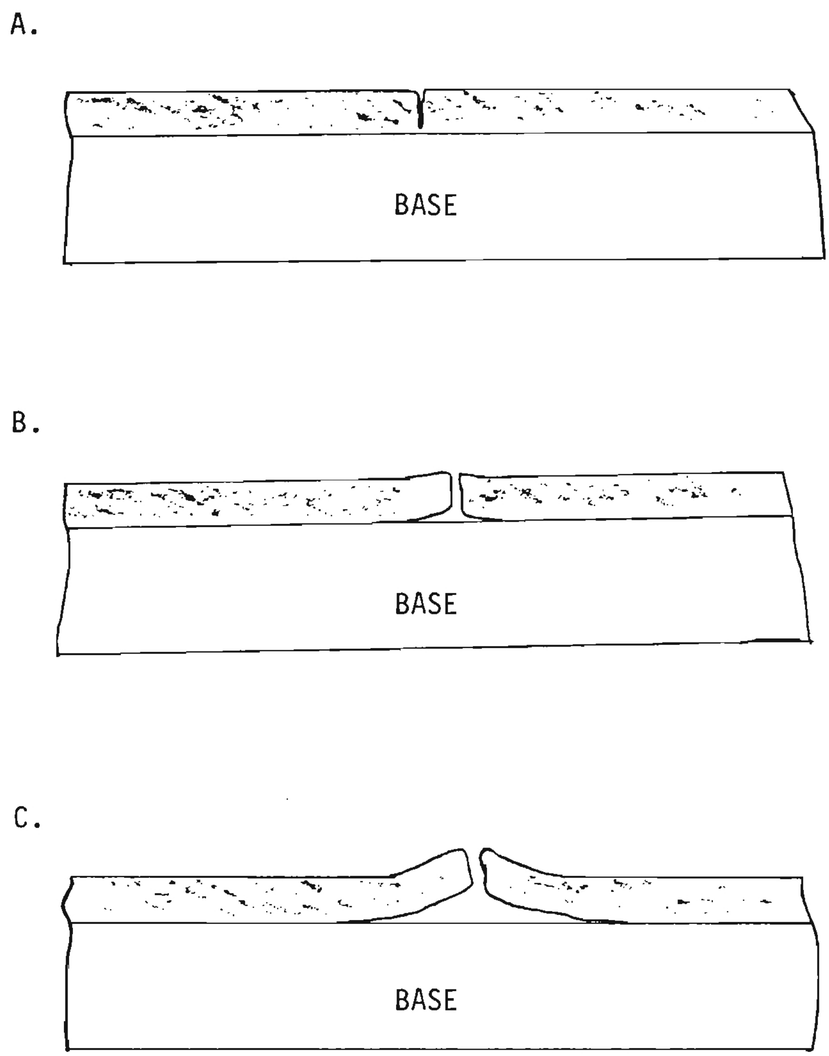

Figure 23.

Schematic Showing Vaulting Due To Loss Of Adhesion At Coating-Base Interface As Crack Growth Proceeds.

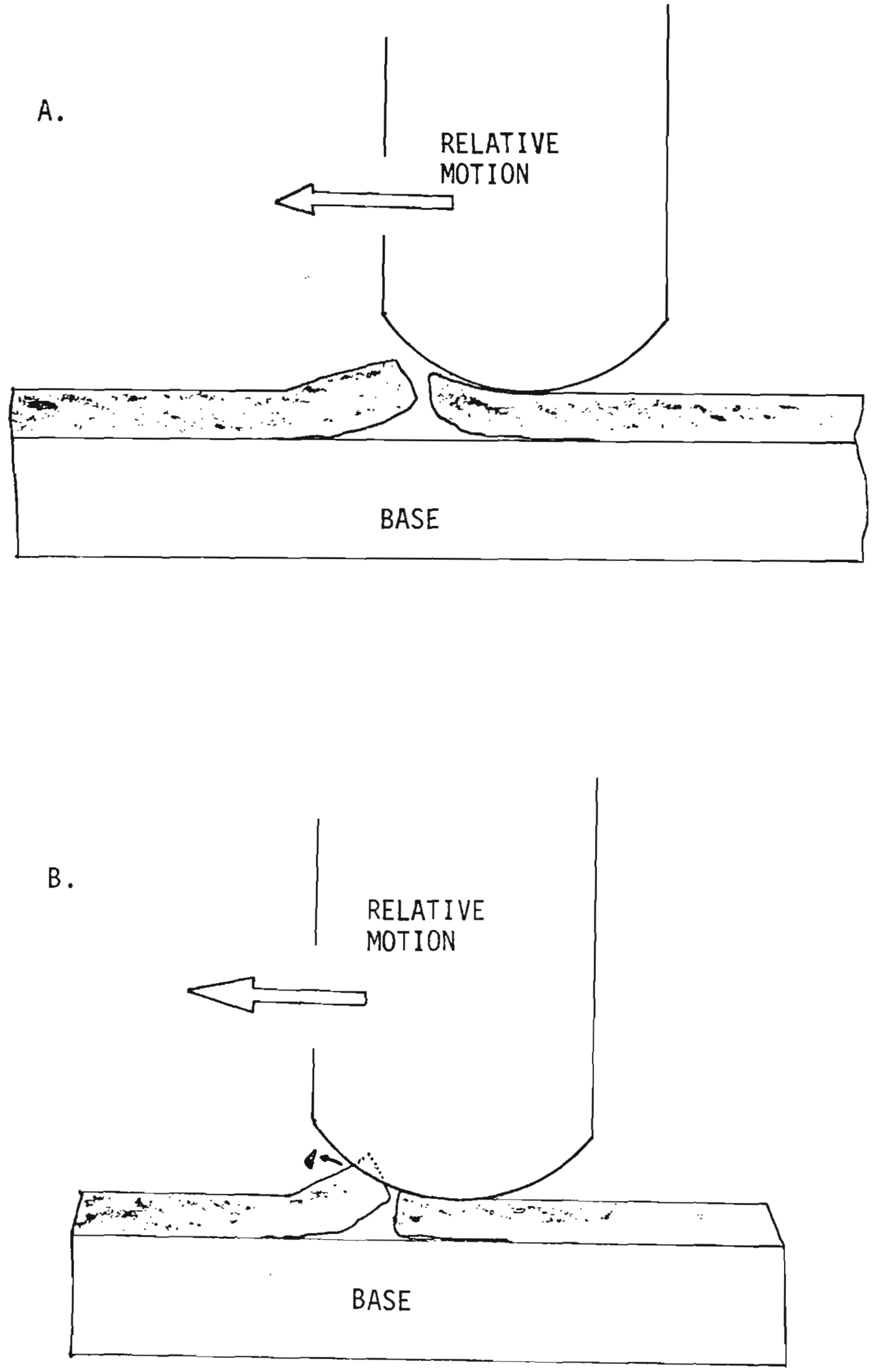

Figure 24.
Schematic Showing Possible Shearing Of Coating Material At Raised Edge Of Crack To Produce Tiny Fragment.

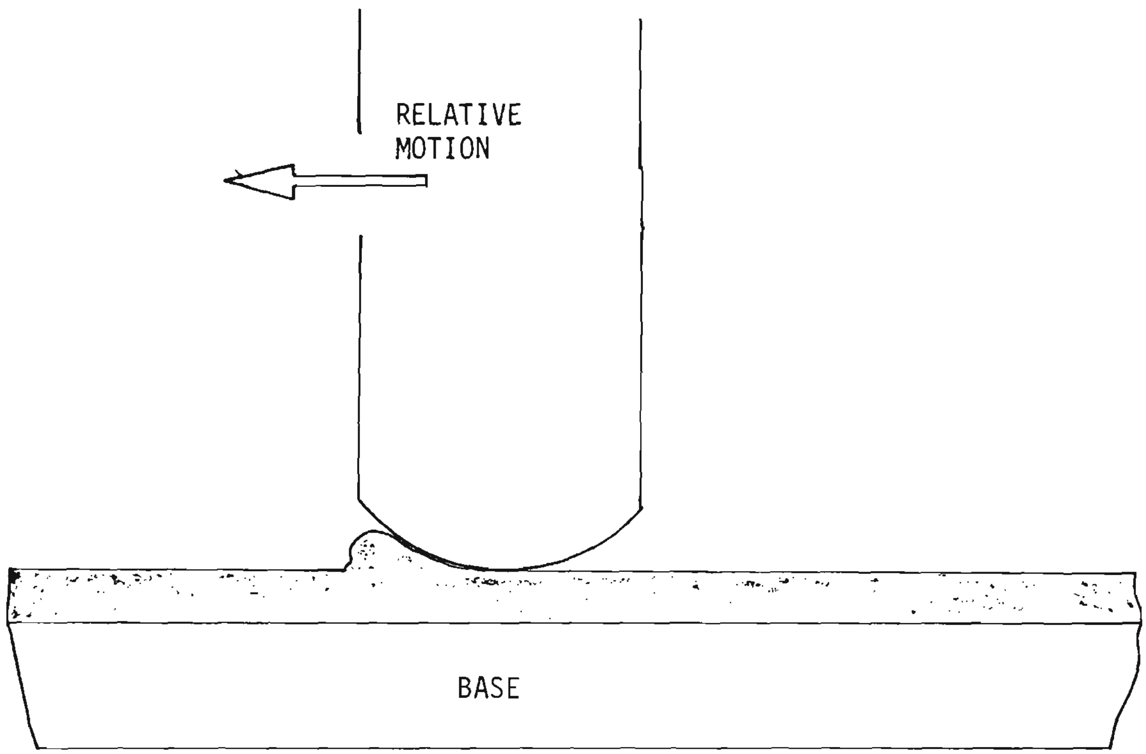

Figure 25.
Schematic Showing Formation Of Prow On Coating Surface At Leading Edge Of Pick-up Element.

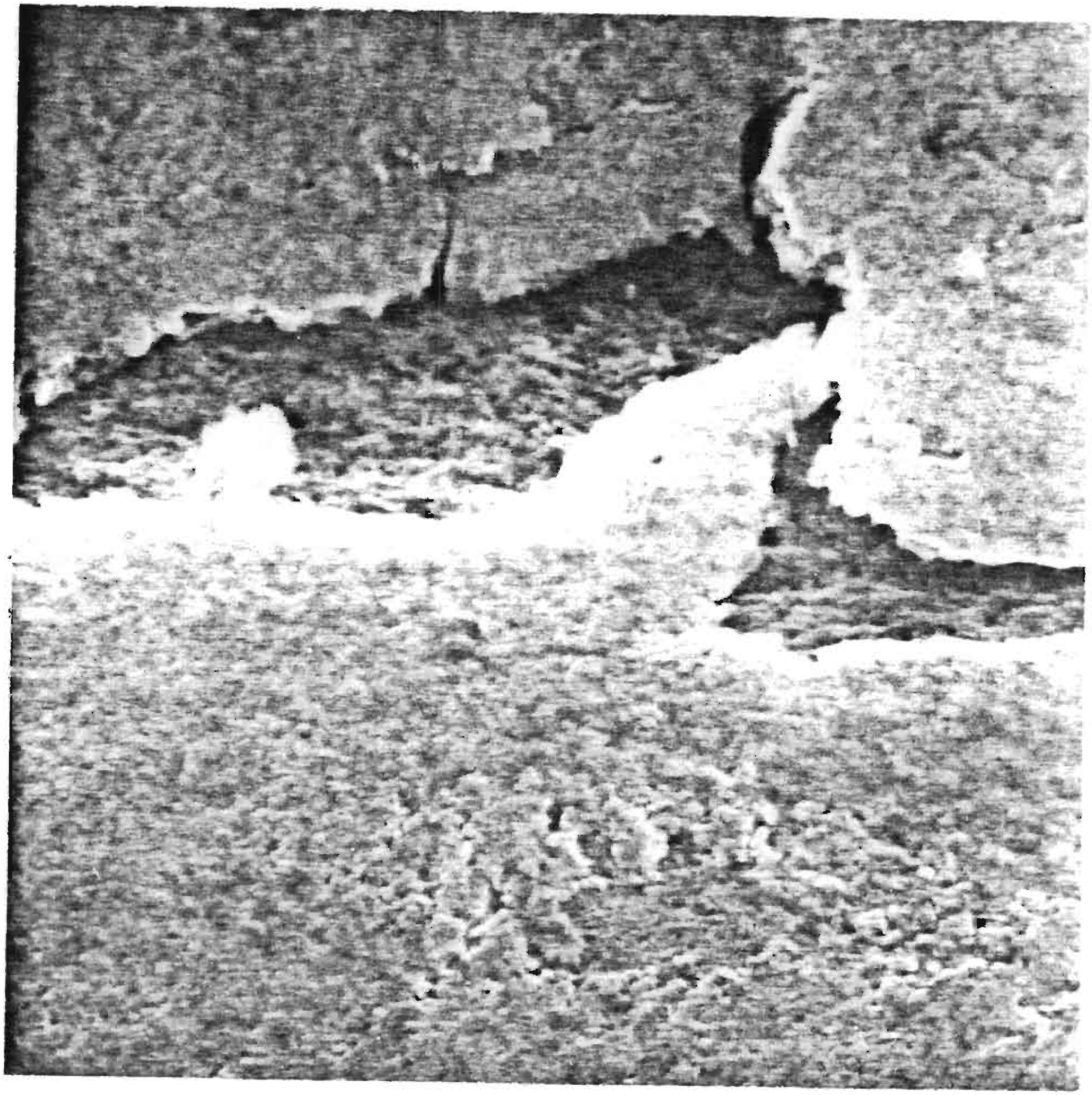

Figure 26. SEM Micrograph Of TDK Tape Surface After Accelerated Wear Test. Note the Extensive Redistribution Of Coating Material And Strong Likelyhood Of Fragments Being Released On This Surface. 22,000X.

III. Magnetic Property Investigations

Novel techniques for the magnetic analysis of magnetic tapes and paints were investigated. Three of these proved valuable for the analysis of recording tapes. First, the anisotropy in properties of an aligned liquid sample was investigated by measuring the torque as a function of the angle of the sample with the magnetic field. These measurements were described in detail in the first quarterly report. The measurement field should be small to prevent reorientation of the particles. Two measurements, the maximum torque and the change in maximum torque during measurement cycles, were correlated with mixing times. The particle distribution analysis was applied to determine the distribution of particle orientations which was then found related to the "quality" of dispersion.

The second technique became possible with the development of the magnetic field pulse apparatus. A novel instrument capable of producing fast field pulses of up to 4KOe with rise times of less than 100 sec was designed and fabricated during the third and fourth periods. This instrument is capable of producing, under computer control, complex magnetic field waveforms. These waveforms mimic the waveforms used in magnetic tape alignment. This device can also produce new waveforms which might be of benefit in tape production. The effectiveness of a particular waveform for particle alignment can be demonstrated with this equipment. For the first time the alignment history during the "standard" alignment was measured. It showed, as described in the third quarterly report, that the particles become disoriented during the period just after the field reversal when the field strength is below the particle coercive force. This suggests that with the standard alignment field the switching time of the field is sufficiently slow to allow the particles to rotate enough to cause disalignment. A series of samples representing different stages of the field waveform can be created to allow discovery of the rotation times necessary for the particle "flipping" phenomenon. This time can be calculated theoretically for an isolated particle; however, in magnetic tape paints the densities of particles are so great that the particles become entangled and cannot move without interactions. This makes a theoretical calculation of the flipping time impossible. The magnetic field pulse unit can be used to prepare samples of different field reversing times thus the flipping time can be measured. A series of samples has been made to measure this time. They will be examined if time is available later. The magnetic pulse unit functioned very well for a prototype; however, improvement could be made in the next generation model.

The final and perhaps most significant magnetic technique developed during the year was the development of analytical methods to calculate the distribution of particle easy axis orientations from the magnetic torque curves. The theoretical development of this analysis was given earlier; therefore, only the primary equations will be listed here:

L = (l1, l2, l3 ....): li is the ith Fourier coefficient of the torque curve.

a = (a1, a2, a3, ...): aj is the jth Fourier coefficient of the effective torque due to a single particle.

(A) a = L: (A) is a matrix whose coefficients can be calculated if the distribution of easy axis orientations of the sample (whose torque curve is L) is known. (3)

r = (r1, r2, r3, ...): rj is the jth Fourier coefficient of the distribution of particle easy axis orientations of the sample whose

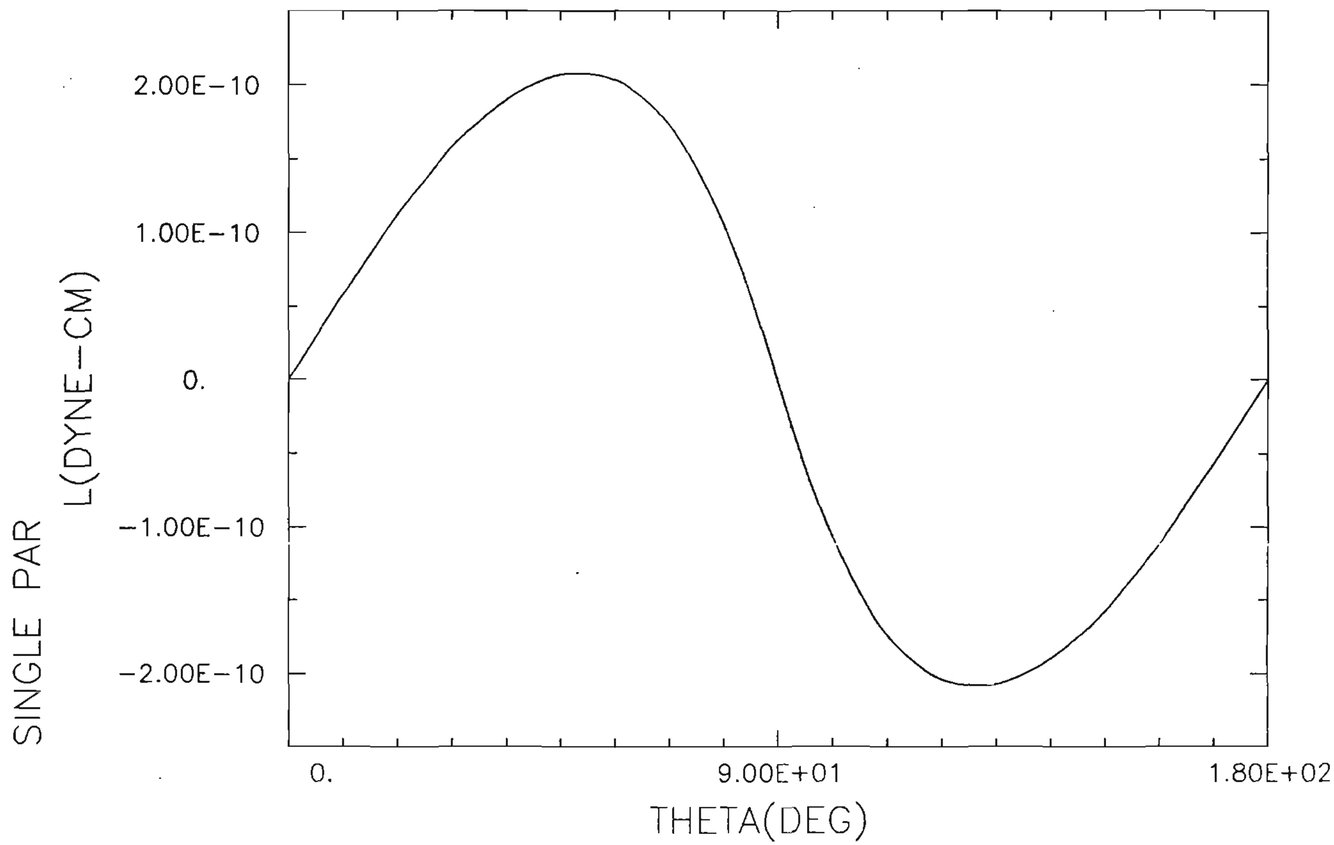

Figure 27. The Effective Torque Due to a Single Magnetic Particle. Calculated from the Torque Curve of a Highly Aligned Sample.

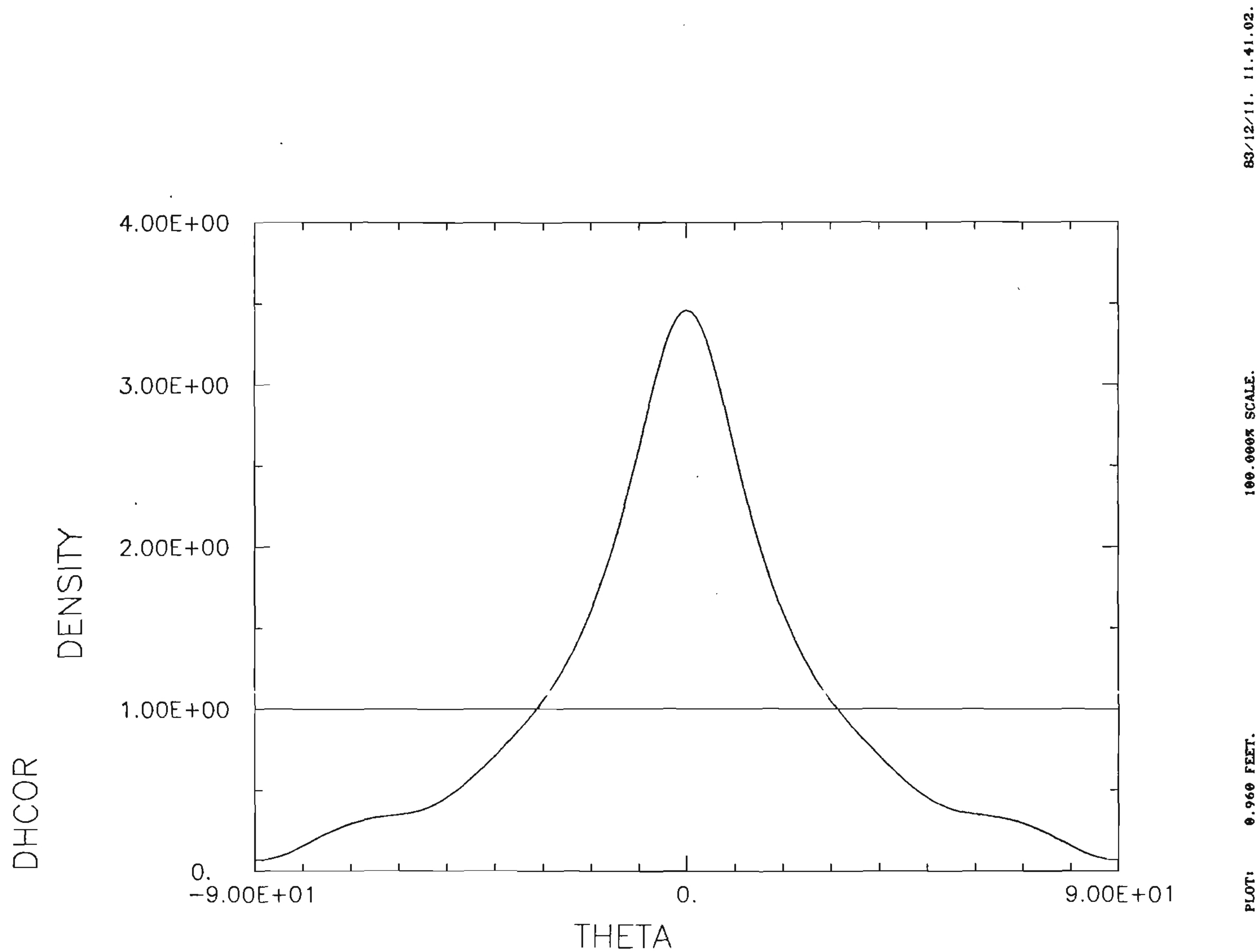

Figure 28. The Calculated Particle Alignment Distribtuion Achieved Using the Hand Coater (The Straight Line Represents a Random, Uniform, Distribution).

50% of the particles being within 40° of each other i.e. within 20° of the axis of alignment. This is far from a complete alignment. Samples highly aligned with most particles within 5° of the alignment axis have been made. These samples, were not suitable for tapes.

The tape sample from the hand coater, which received no magnetic alignment, is aligned by purely mechanical interactions. (Figure 29). The velocity gradient created in the paint when coating the base film cause alignment parallel to the direction of tape movement. This alignment mechanism should and does occur with the wire coater. (Figure 30) The alignment caused by the wire coater is less than that produced by the hand coater. Qualitative analysis of the differential velocities during coating suggests that the alignment caused by coating should be enhanced for thinner coats and for higher tape velocities during coating. These trends can and should be experimentally verified and characterized. These features may be valuable in tape production technology as this "prealignemnt" certainly effects the final alignment.

The magnetic pulse unit was used to produce tape samples using a 3KOe, 200 msec waveform similar in shape to that used in production and in the hand coater. Figure 31 shows a comparison

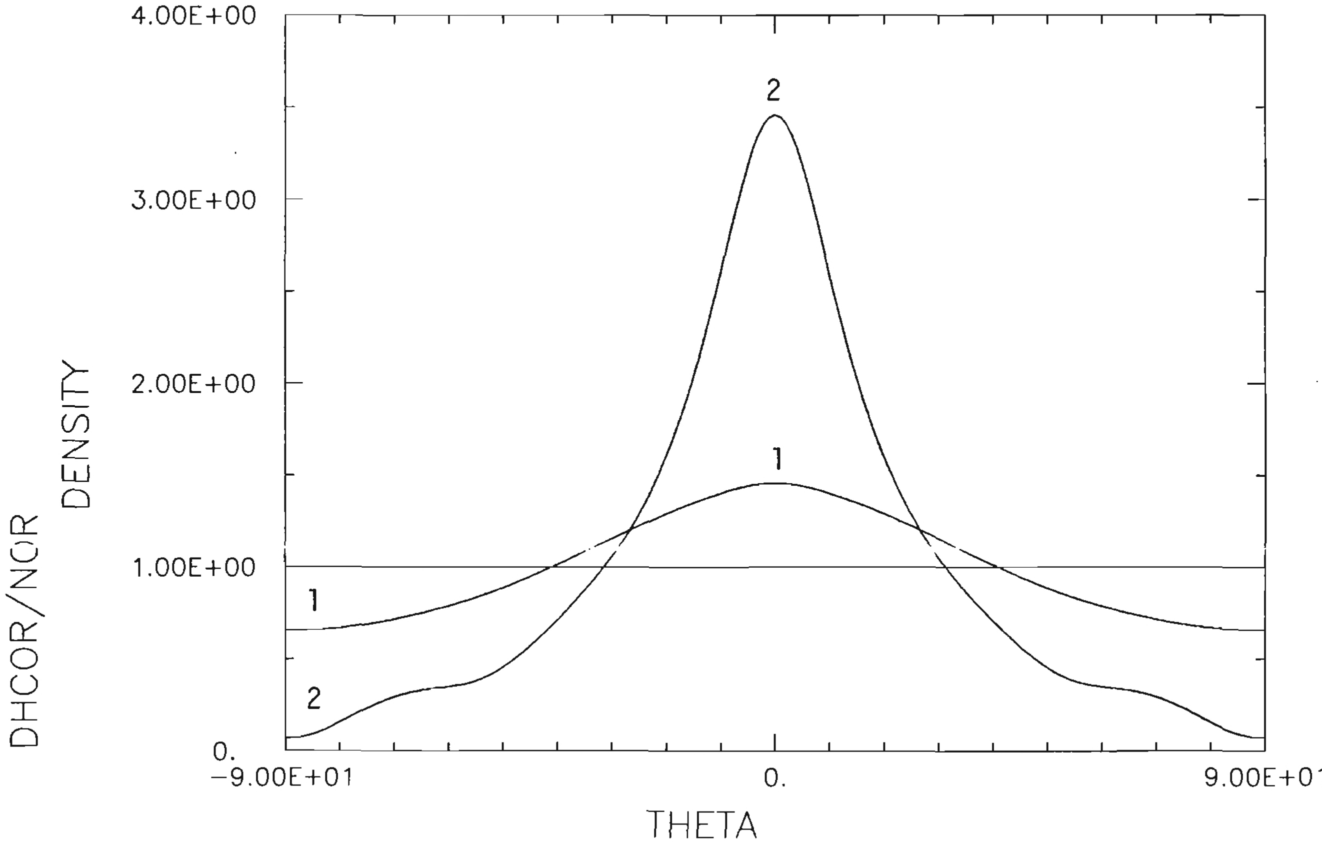

Figure 29. Alignment Distributions Achieved in the Hand Coater.

1. Prior to Magnetic Alignment.
2. After Magnetic Alignment.

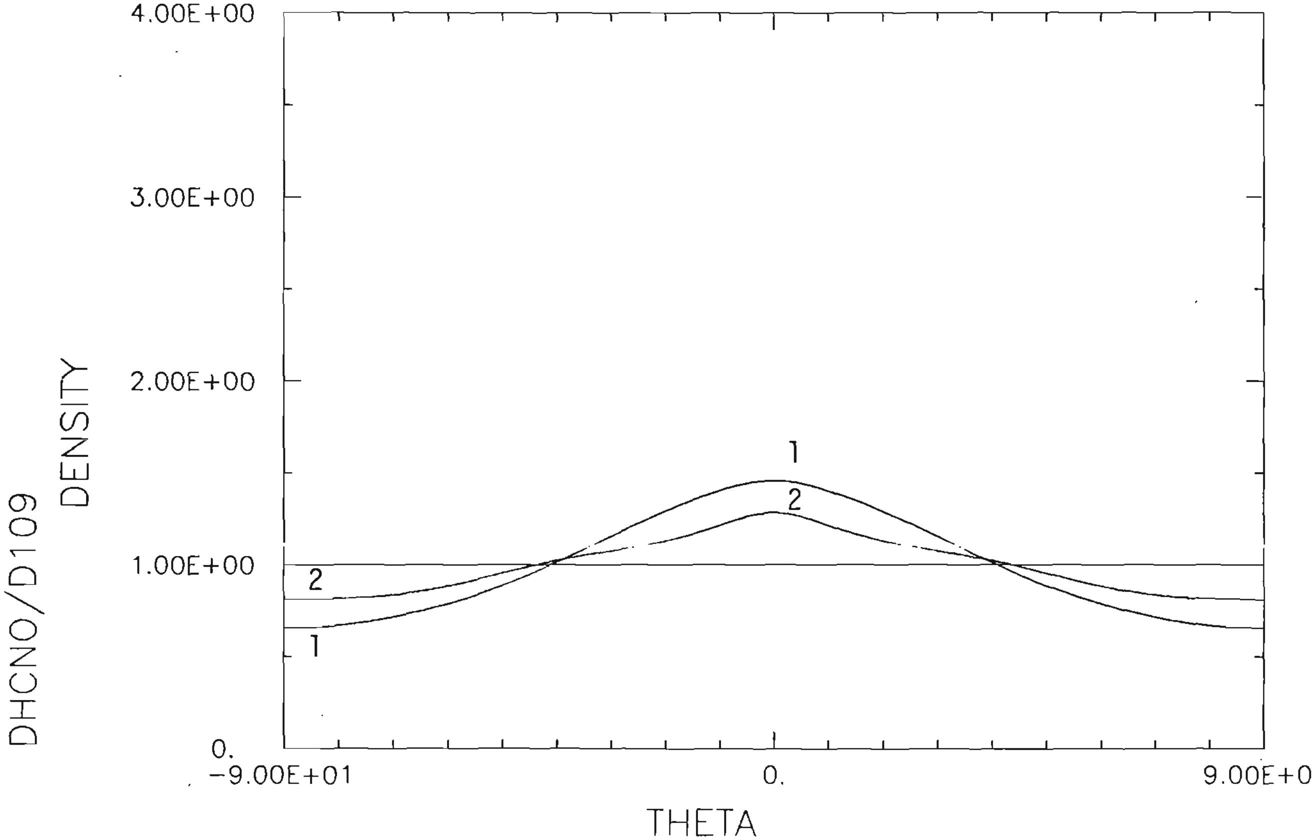

Figure 30. Prealignment Distributions Caused by Coating Method.

1. Hand Coater
2. Wire Coater

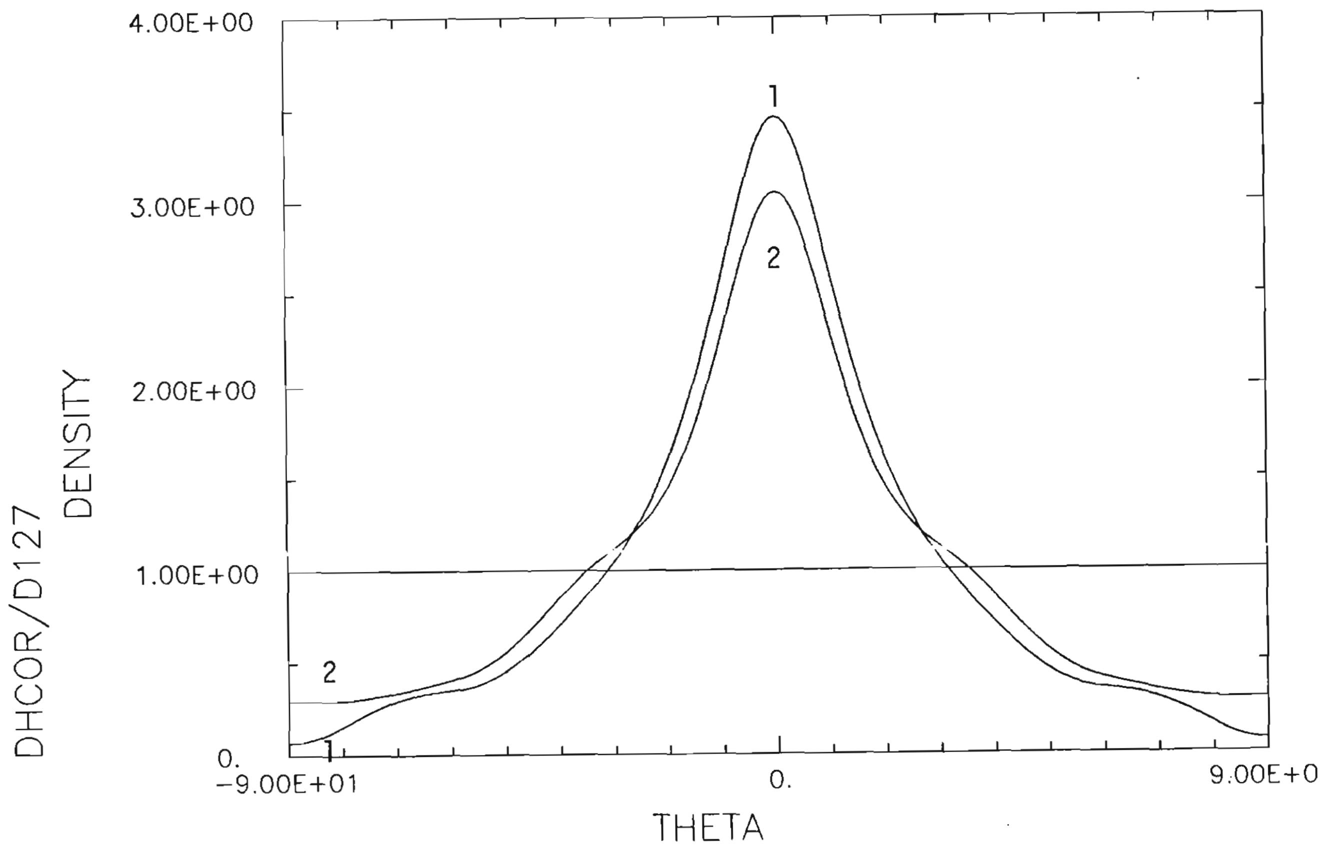

Figure 31. Final Alignment Distributions Achieved with:

1. Hand Coater
2. Field Pulse Unit using 3KOe, 200 msec Standard Waveform.

of distributions obtained with the magnetic pulse apparatus and the hand coater. The slight disagreement could be due to differences in the initial orientation effects of the hand coater and the wire coater or else to the time difference between coating and field application. The magnetic pulse unit was used to produce other waveforms. The distributions of two of these, a 4 KOe "standard" waveform and an "AC" waveform are shown in Figures 32 & 33 respectively compared to the 3KOe waveform. The AC waveform showed no significant difference from the 3KOe waveform; however, the 4KOe had a different shape but nearly the same magnitude of alignment.

One of the most useful features of the magnetic pulse unit is its ability to "freeze" the alignment at various points in the aligning waveform. With this feature the alignment history can be monitored. The alignment distribution for the 3KOe standard waveform is shown in Figure 34 at four points:

1) after coating just before magnetic alignment
2) near the highest point of the forward field
3) during field reversal when the reverse field is less than the coercive force.
4) after complete alignment

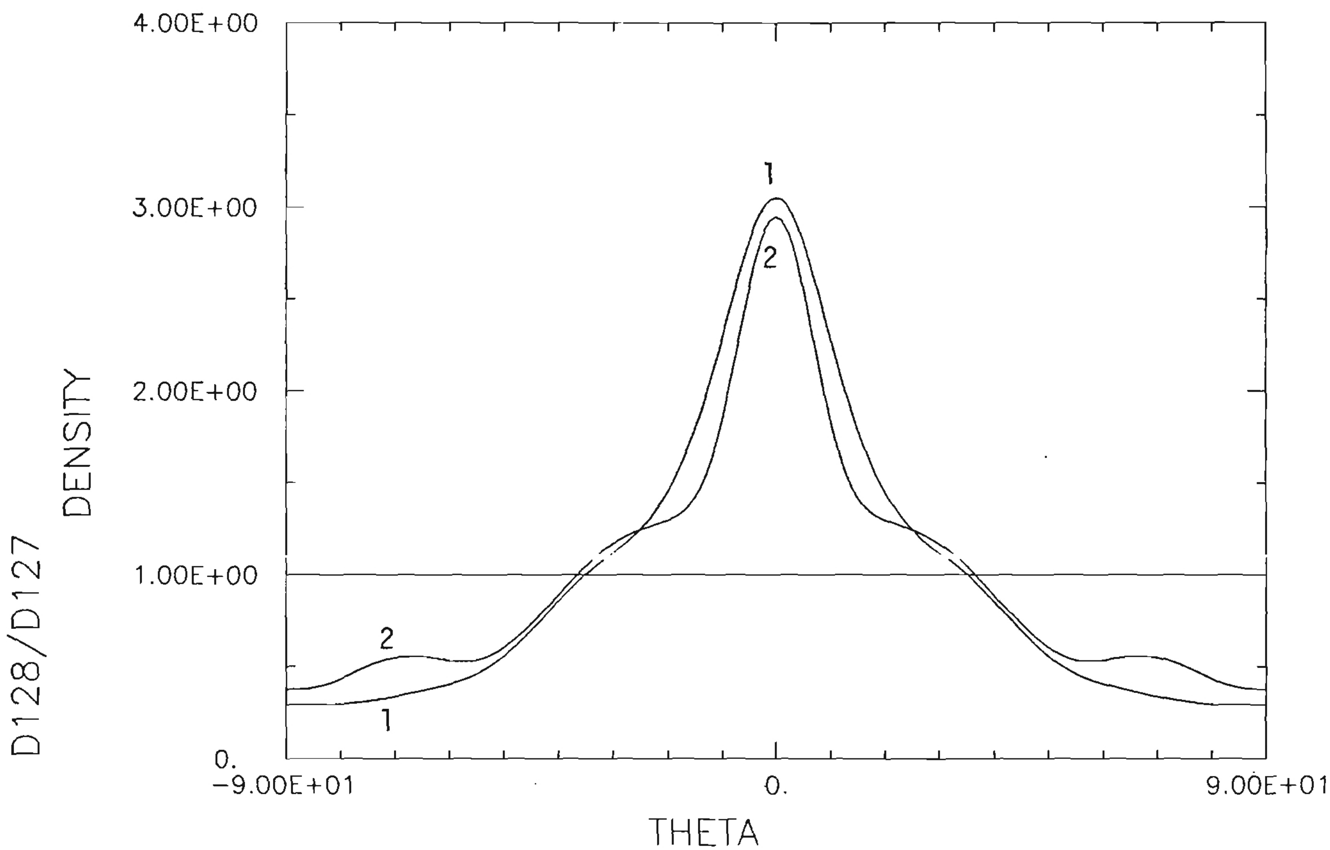

Figure 32. Final Alignment Distributions Achieved with the Field Pulse Unit Using 200 msec Standard Waveforms of: 1. 3KOe 2. 4KOe.

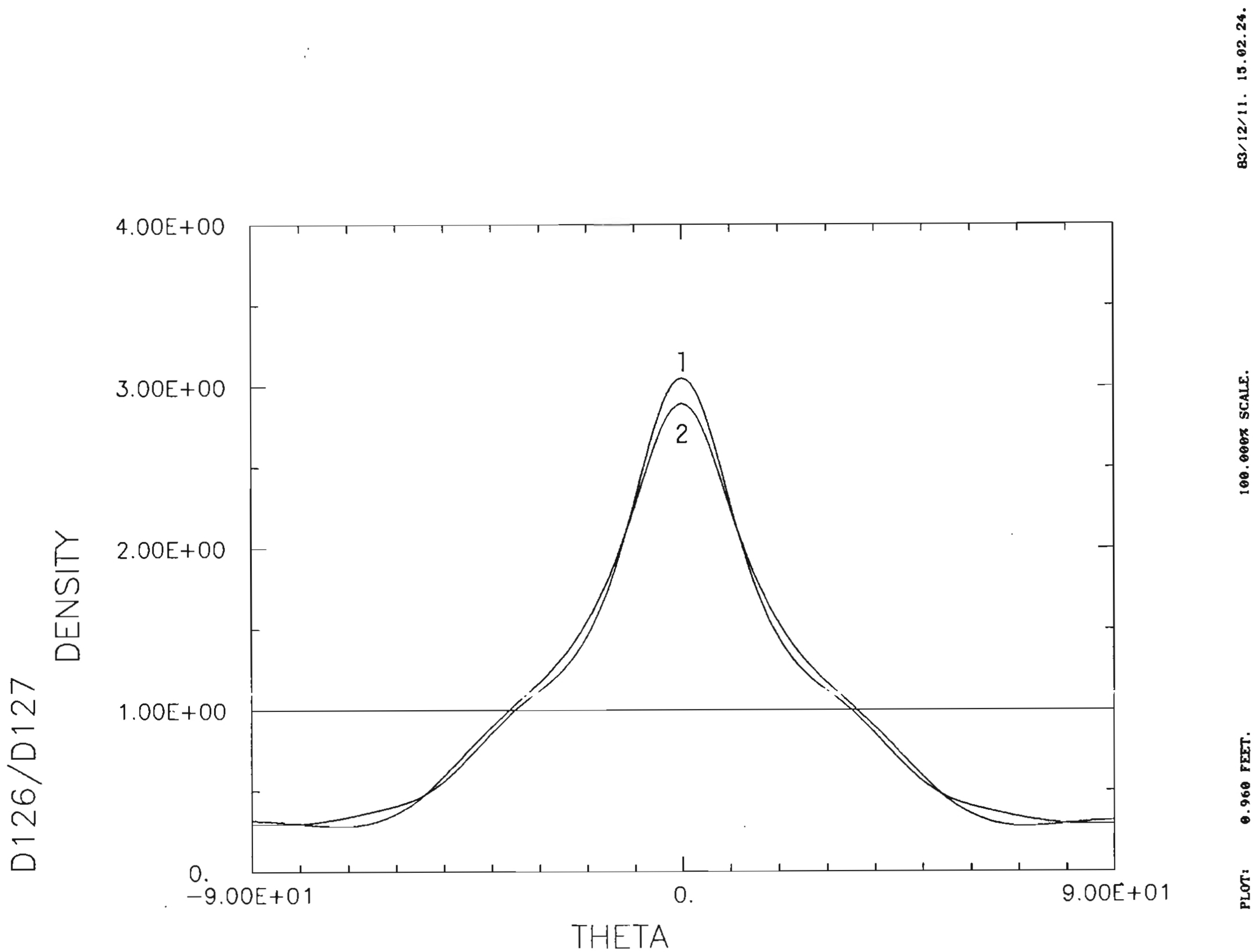

Figure 33. Final Alignment Distributions Achieved with the Field Pulse Unit Using:

1. 3KOe, 200 msec Standard Waveform
2. 3KOe, 200 msec AC Waveform

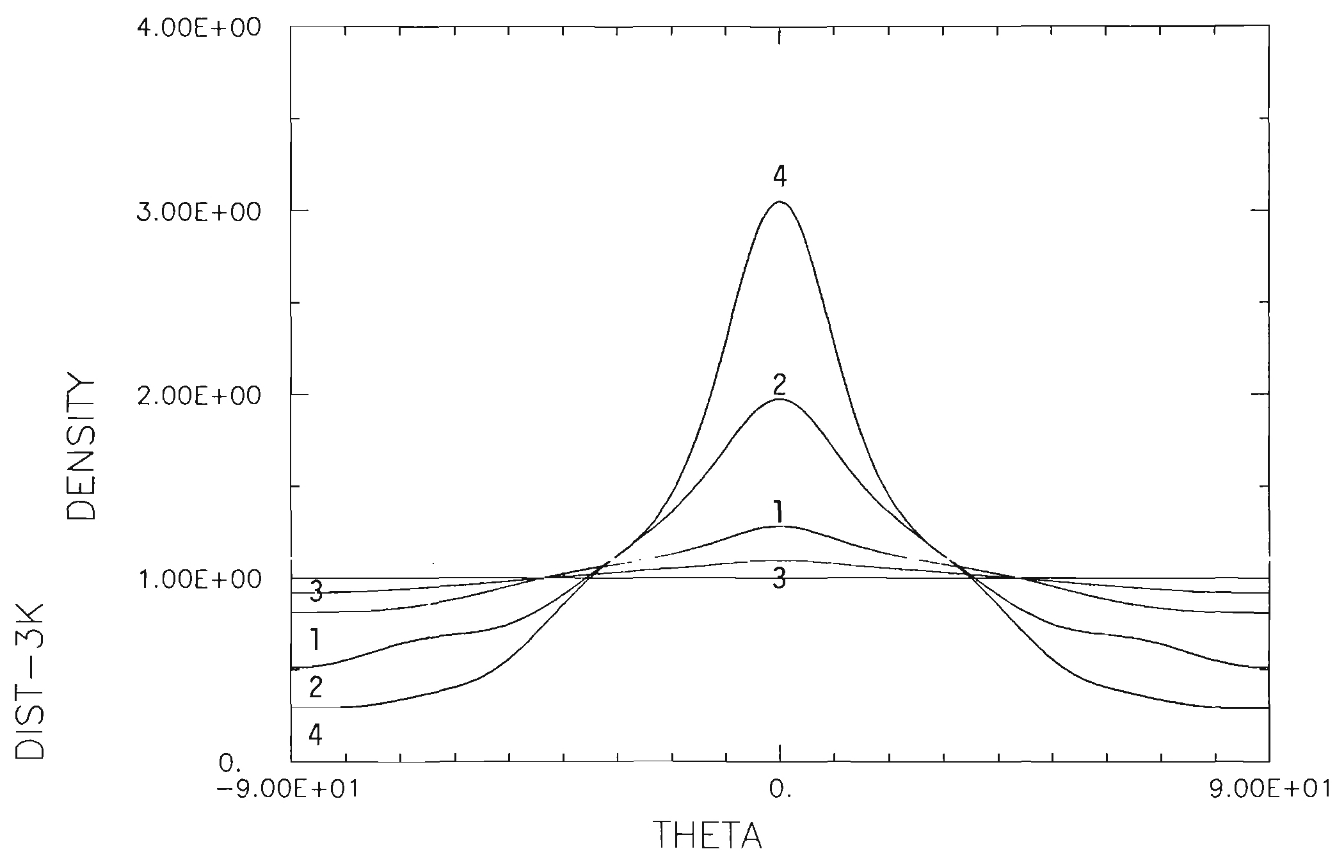

Figure 34. Alignment Distributions Achieved at Various Stages of the 3KOe, 200 msec Standard Waveform.

1. Prealignment Due to Coating
2. At the Heightest Point of the Forward Field
3. Just After the Field Reversal with the Field below the Coercive Force
4. After the Complete Waveform.

This series of distributions shows that the particles are first aligned in the forward field, then disaligned in the reverse field when the field strength is below the coercive force and finally realigned by the remainder of the reverse field waveform.

These preliminary experiments do not provide a complete evaluation of the alignment procedure but they do represent are a significant advance in the current analysis techniques. A series of step waveforms has been used to make several samples which can be used to trace the alignment of particles for most arbitrary waveforms. These will be measured in both high (saturation) fields and low fields (well below the coercive force) if time permits. This set of measurements should allow the prediction of the alignment obtainable from many arbitrary waveforms. If this can be completed a major advance in the understanding of particle alignment will have been achieved.